

ENERGY SYSTEMS AND INERTIAL OSCILLATORS

by

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LIST OF SYMBOLS

<u>Symbol</u>	<u>Definition</u>
R _l	Electrical load resistance
R _s	Electrical source resistance
L	Inductor within an electrical system
C	Capacitor within an electrical system
f _h	Frequency at high end of electrical oscillator bandwidth
f _l	Frequency at low end of electrical oscillator bandwidth
f _o	Intrinsic frequency of oscillator
f _r	Resonant frequency of circuit, same as f _o
DD	Total darkness 24 hours/day
LD	Combination of light and darkness during the day
BW	Bandwidth of oscillator
P	Potential component of clock or oscillator
K	Kinetic component of clock or oscillator
DT	Differential time

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The objective of this dissertation was to analyze the effect of inertial oscillators in energy systems. Traditionally defined in differential equations for hardware, generalized systems diagramming is used to extend the knowledge of inertial mechanisms to environmental systems. Equations and diagrams are presented together, first in definition and review, then as elements that are incorporated in ecosystem patterns.

Starting with the simplest configurations, inertial elements were combined into oscillators and these into ecosystem configurations. Each model uses computer simulations to characterize response in the time and frequency domains. A unit oscillator mechanism was included as a clock mechanism in ecosystem prototypes. Potential for this kind of a mechanism was considered in competition, energy selectivity (the ability

to acquire energy input in a selective manner through use of an inertial oscillator), diversity, and survival of systems. For each model, diagrams, equations, time simulations, and frequency responses are given.

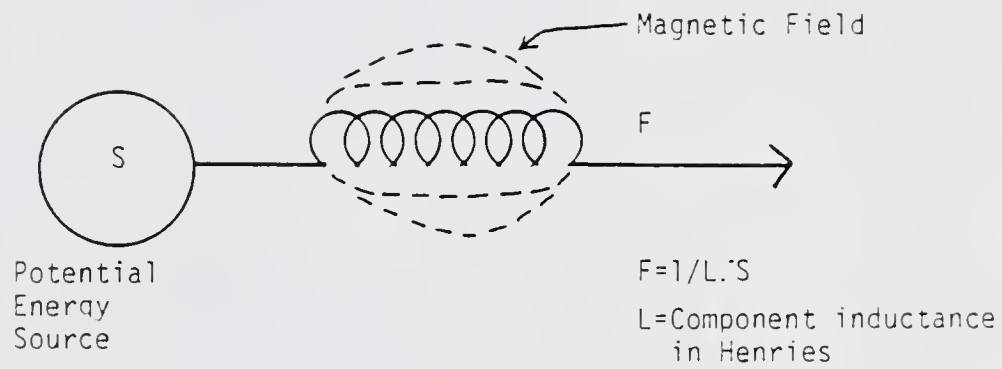
The results indicate that the development of an internal oscillation, accomplished for this research by an autocatalytic inertial oscillator, increases the efficiency of energy acquisition within a range of acceptable frequencies, increases power transfer for the system to other systems within the ecosystem, increases ecosystem diversity, and provides the system with a greater competitive advantage within its niche. The most competitive system is produced as a result of its ability to generate multiple internal rhythms that it then employs to better time changes in its environment. Competitive coexistence and exclusion are produced by combinations of system configurations employing internal inertial oscillators.

INTRODUCTION

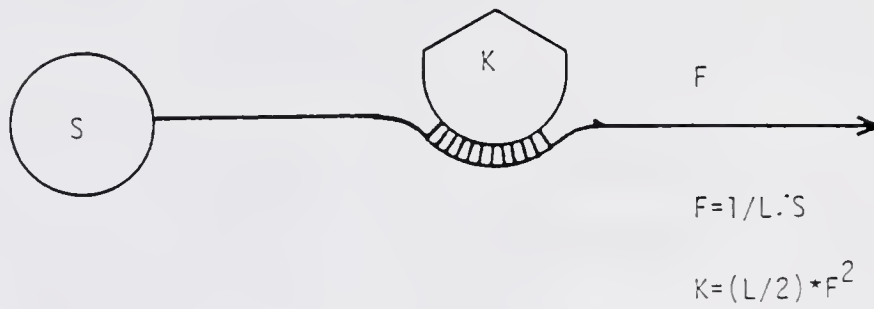
This research is a direct outgrowth from an understanding of the operation of some simple oscillator systems. Knowledge of the energy and power input and transfer characteristics of simple oscillators lead to the idea that many if not all systems employ a combination of inertial components to produce internal oscillations. In many configurations that use inertial elements, inertial oscillators are formed. Since backforce actions are known in the behavior of biological and social systems not involving hardware, inertial elements and oscillators may exist in environmental systems or may be available for ecological engineering designs of environmental systems of the future. Therefore, this dissertation is a study of the role of inertial elements and inertial oscillators in basic configurations of ecosystems.

Traditionally defined in differential equations for hardware, generalized systems diagramming helps the extension of existing knowledge on inertial mechanisms to environmental systems. In the following sections equations and diagrams are presented together, first in definitions and review, then as elements that are incorporated in ecosystem patterns. The simplest inertial element and its equations are shown in Figure 1. An important characteristic of this simple inertial component is the integral dependancy of the flow (F) through its pathway. The flow through this inertial component is dependent upon the value of its inductance (L) and the integral of the potential energy (S) forcing the flow through the pathway. The energy stored in the

Figure 1: Fundamental inertial component. The figure shows the simplest inertial component. Inertial backforce is generated by the component as a result of its induced magnetic field. The equations describe the flow through the inertial component and the energy stored by the component in its magnetic field.



(a)



(b)

magnetic field around the element is related to the inductance of the component (L) and the square of the flow (F). It is the energy stored in the magnetic field of the inductor that opposes any change in flow through the element. The opposition to changes in the flow through the element, by the fluctuating magnetic field, produces the inertial backforce generated by the element.

In this study system configurations with inertial mechanisms and oscillators were analyzed and related to the design of environmental systems. The energy circuit model simulations and plots explain and/or define the concept of energy-selective power utilization and transfer. First, two simple oscillator models are presented, one an electrical resistance-inductor-capacitor circuit, and the other a mechanical mass-spring-damper model. Second, an autocatalytic inertial oscillator is shown. The autocatalytic inertial oscillator model provides a means of introducing an internal control behavior into energy circuit systems which in turn produce energy-selective behavior within models of energy circuit producers and consumers. Next, the simulations for models of energy-selective competition are shown. This series of models analyzes the advantages or disadvantages of energy-selective behavior for individual producers in competitive situations. The model simulations also aid in developing an insight into the overall system benefits from an individual system's energy-selective behavior. The last series of model simulations examine the effects of including inertial oscillators into a salt marsh located in New Zealand. The model was previously calibrated with biomass data and simulated seasonal productivity (Campbell, 1984). The Kaitun marsh simulations are the result of modifications to the original Kaituna marsh model. Energy selective

producers are substituted into the marsh model in place of the original non-energy-selective producers in order to analyze the effects of energy selective behavior within a known system. Following the insertion of energy-selective behavior into the Kaituna marsh model, the effect of competition is shown by the addition of competing energy-selective producers into the modified marsh model.

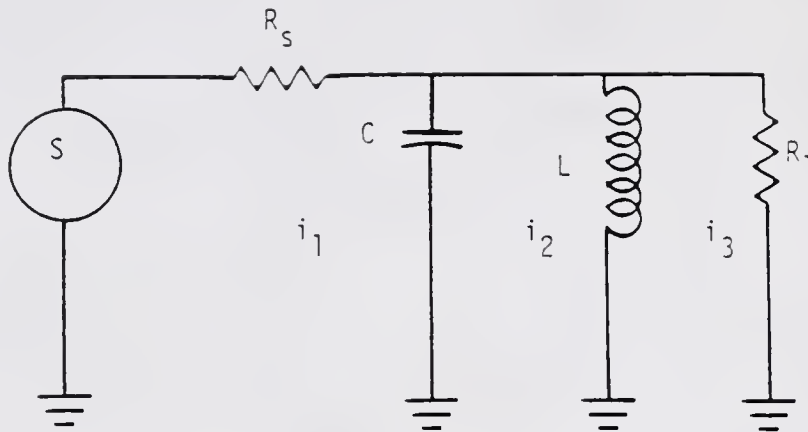
Previous Study of Electrical and Mechanical Inertial Mechanisms

The ability to act with a behavior that produces a selective acquisition of input energy relies upon the ability of the system to produce internal oscillations. The simple electrical and mechanical oscillators provide an example of the concept. Electrical circuits that exhibit their own internal inertial oscillations are called bandpass oscillators or filters, blocking filters, tuners, receivers, or simply oscillators. One example of a mechanical oscillating system is an automobile's suspension system.

Figure 2 shows the electrical bandpass oscillator, first with electrical diagramming and second with energy circuit diagramming. The differential equations for both diagrams are presented. The inertial generated oscillation is the result of a transfer of energy internally between the two components of the system, the capacitor (C) and the inductor (L). Interestingly the period of the free-running oscillation is directly related to the two components (C) and (L) and not to the rate of flow of the electrons.

The frequency setting coefficient k_3 is a constant and may be calculated using two different methods. The first method is the most direct and is solely dependent upon the inductance (L) and capacitance (C) of the circuit (see equation 6). The second method relies upon

Figure 2: The electrical inertial oscillator. The figure shows both the electrical diagram and the energy circuit for this inertial oscillator. The equations describe the rate of change of the charge (storage Q) in the oscillator. The frequency setting coefficient k_3 is a constant for flow through pathway F_3 and is calculated from the system component values. Coefficient k_3 may also be calculated from the free-running period of the inertial oscillator. Figure (a) is the electrical diagram. Figure (b) is the energy circuit diagram.



$$dQ/dt = 1/R_s * (S - (Q/C)) - (1/R_1 * C) * Q - 1/(L * C) * Q$$

$$i_1 = 1/R_s * (S - (Q/C))$$

$$i_2 = (1/L * C) * Q$$

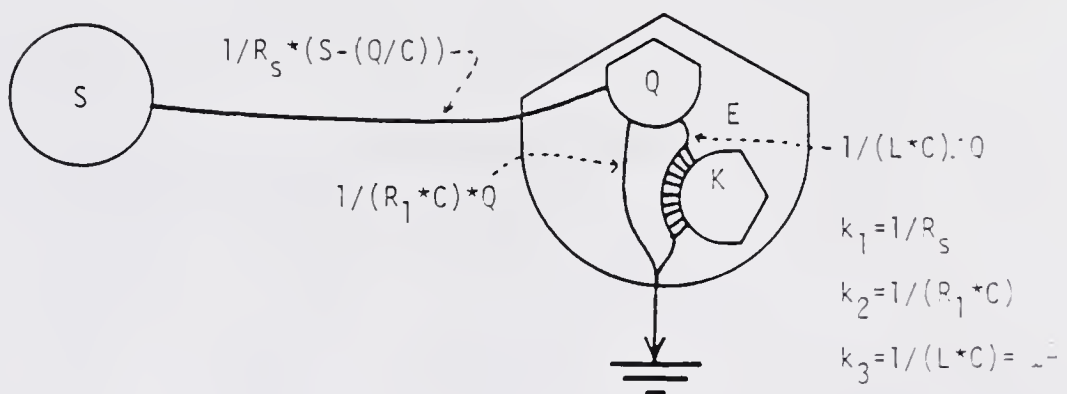
$$i_3 = (1/R_1 * C) * Q$$

$$\omega = 1/(L * C)^{0.5}$$

$$\omega^2 = 1/(L * C) = 2.0 * f_0^2$$

Q = storage of charge in capacitor (C)
 C = capacitance (Farads)
 L = inductance (Henries)
 f_0 = intrinsic frequency of the oscillator

(a)



$$dQ/dt = 1/R_s * (S - (Q/C)) - 1/(R_1 * C) * Q - 1/(L * C) * Q$$

$$dQ/dt = k_1 * (S - (Q/C)) - k_2 * Q - k_3 * Q$$

$$\text{Energy in } Q = Q^2 / (2 * C) \quad \text{Energy in } K = (L/2) * (1/(L * C) * Q)^2 = Q^2 / (2 * L * C)$$

(b)

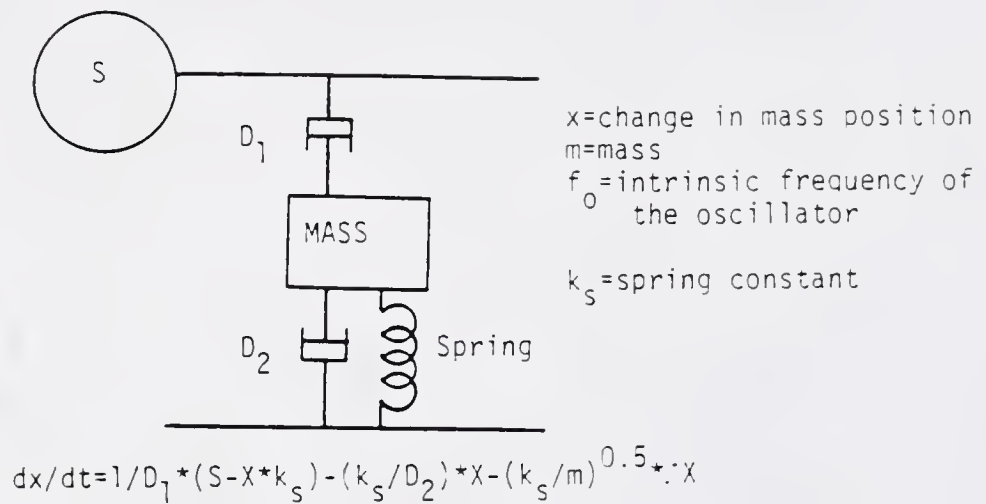
being able to discern the free-running period of the circuit. Equation 6 also provides the calculations for period method to determine k_3 . Which ever method is employed to calculate frequency setting the end result is that k_3 is a constant and not a variable flow coefficient.

Figure 3 shows the mechanical mass-spring-damper inertial oscillator. The figure presents the mechanical diagram and the energy circuit diagram with their accompanying differential equations. The mechanical oscillator is much like the electrical oscillator and with the exception of the system components and units has differential equations that are much alike.

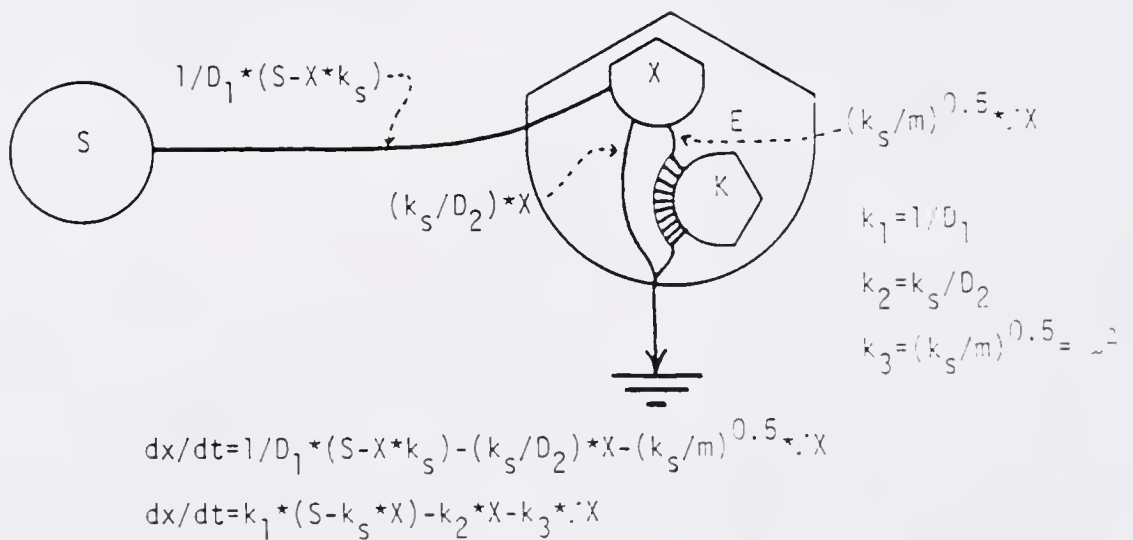
The frequency setting coefficient (k_3) for the mechanical oscillator may also be calculated using two methods, and is a constant and not a variable.

The previous figures clearly show that the basic design for development of an internal oscillation in simple inertial oscillating systems is the combination of two components that act in a reciprocal manner. These components, one potential and the other kinetic combine to transfer energy between themselves and as a result provide their system with an internal inertial oscillation. Furthermore, the simple oscillator systems, such as the electrical and mechanical oscillators, maximize their power transfer in the most efficient manner when the period of their internal oscillations exactly match those of their external supply. When the period of the system's internal oscillation is longer or shorter than that of its energy source, the power transfer and power input to the system decreases.

Figure 3: The mechanical inertial oscillator. The figure shows the mechanical diagram and the energy circuit model for the mechanical inertial oscillator. The equations describe the rate of change of the mass position (x). The coefficient k_3 is a constant for setting the period of the system oscillation and is calculated from the system components or from knowing the system free-running period. Figure (a) is the mechanical diagram and (b) is the energy circuit diagram.



(a)



(b)

Previous Studies of Inertial Mechanisms In Environmental Systems

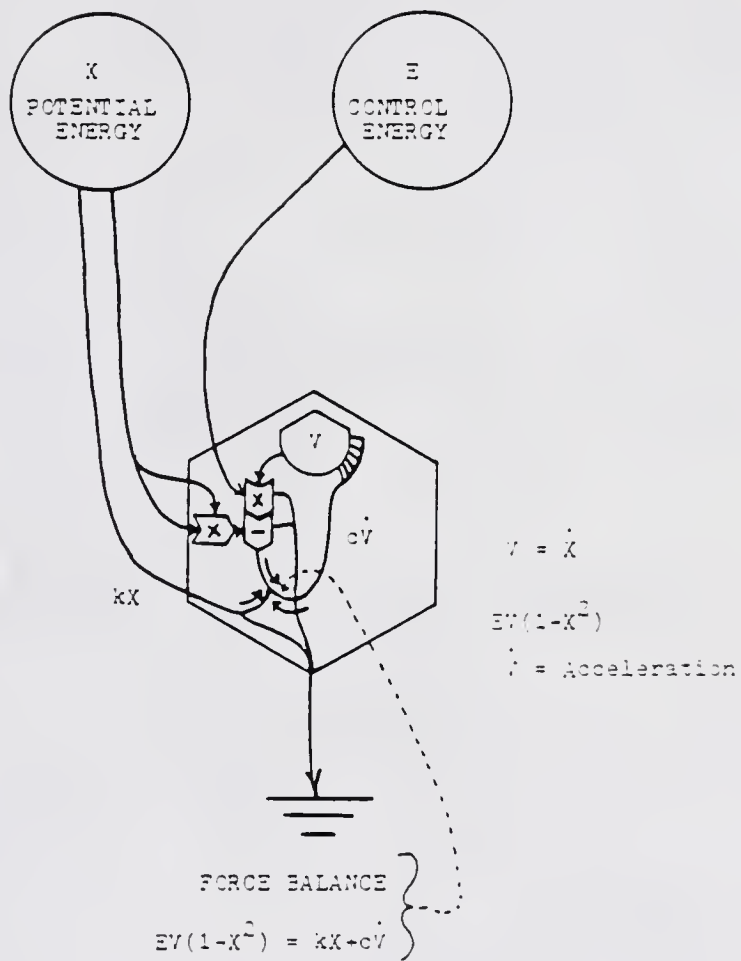
Alexander 1975, studied the cycles of order and disorder producing a quantitative theory based upon energy analysis for global cycles, surges, and disasters. Storms, earthquakes, urban fires, floods, volcanic eruptions, wars, and forest fires were modeled. Order and disorder were recognized as component parts of a cycle that employed disorder to recycle ordered material to stimulate new growth within the system. A global model was employed by Alexander (1975) to indicate the effects of the cascading of catastrophic events within a web system.

One particular model developed by Alexander (1975), the Exponential Surge Model, was employed to simulate actual disaster processes. The model, produced a pulsed self-started disorder, thereby recycling order to disorder and producing a new growth period.

Campbell 1984, investigated the role of ecosystem structure in absorbing or filtering external energy inputs to the ecosystem. The organization of system filter properties was shown to provide the ecosystem with the ability to adapt to a variety of input frequencies. Turnover time for the structural storages within a system when matched to the input energy frequencies usually determined the power capture of the system. Furthermore, Campbell discovered that the high frequency cutoff of the individual components in an ecosystem and their particular resonant peaks were determined by the turnover time of their structure. However, these oscillators do not involve inertial elements.

In his book Systems Ecology: An Introduction Odum 1983, presents a number of models that utilize potential and kinetic components. Odum also developed the energy symbol for inertial response--a bearded tank (Figure 5) (Odum, 1967). The energy circuit model shown in Figure 4 was

Figure 4: Odum's diagram of the Van Der Pol oscillator. The model utilizes a kinetic storage as a backforce to produce the system oscillation. Odum 1983, pages 176-77.



drawn by Odum as a translation of the Van Der Pol oscillator. An oscillation is developed in the system because of the presence of an opposing internal backforce. The system does not contain a potential storage, only a storage of velocity energy, but an oscillation is produced by the interaction of an inertial backforce, a frictional force, and a driving force.

Odum, 1983 further describes the control effect of pulses on timers. Using a model of a mechanical chain which ends in a timing pulse, he shows that timing devices require a reference pulse. The pulse mechanism has a kinetic property in the oscillating wheel. Feedback of this timing pulse provides control to the slower cogwheels in the mechanical chain. The conclusion states, "If most systems develop chains and develop high quality with pulsing delivery of the feedbacks, a clock is automatically provided so that the systems can utilize timing functions" (Odum, 1983, p. 284).

Internal Timing vs External Timing of Inertial Oscillators

Whether the autocatalytic oscillator is environmentally dependent, environmentally sensitive, or completely autonomous has an effect on the way the rhythm is produced. In fact, the major point of contention about biological clocks centers around their utilization of or dependancy upon persistent environmental signals. The two points are best explained by the use of two different types of man-made clocks. The internal autonomous biological clock is likened to an alarm clock. The alarm clock contains all the components necessary to produce internal timing. The operation of the clock is completely autonomous, it keeps time by its own mechanism. The external clock is best described by the sun dial. The sun dial has an internal mechanism but the timing is the

result of an external signal. Therefore the sun dial acts only as a receptor.

In this study the autocatalytic inertial oscillator is an autonomous internal oscillator with a free-running rhythm. The oscillator produces rhythmic activity that will persist for some time without any environmental cues. The development of energy-selective behavior may require that a system possess the ability to sense changes in its environment. With this in mind, the autocatalytic inertial oscillator senses its environment and its activity responds to changes in that environment. The importance of possessing an internal oscillator that has its own free-running rhythm and is capable of sensing and changing with its environment is studied in this research. The ability to acquire energy in a selective manner may depend (among other characteristics) upon a system's ability to generate an autonomous internal rhythm which senses changes in its environment and responding to those changes.

Definition of Energy Selectivity

The "principle of energy selectivity" could be stated as follows. When a system is subjected to a cyclic energy input from its environment the system will best insure its ability to obtain energy by developing an autonomous internal rhythmic behavioral guide that is capable of sensing its environment. The closeness of the system's internal rhythm to that of its primary environmental cue determines the system's energy acceptance ability, and combined with other environmental, internal and system factors its ultimate survivability.

Energy-selectivity may play an important role in the ability of a system to maximize its input energy and power. Since the ability to

acquire energy and power has a direct bearing on a system's ability to transfer power to the next larger system energy-selective behavior would also play an important role in the power transfer among systems. If a system can act in an energy-selective manner that activity may help the system define its niche within the next larger system. One hypothesis for this research is that energy-selective behavior provides a system with a means of maximizing its input power, and as a result a means of maximizing its power transfer to the next component or larger system. Within biological systems, the ability to act in an energy selective manner provides the system with a means for allocating input energy among the various subsystems. The ability to allocate input energy may allow the formation of a greater variety of niches, thereby increases system diversity and maximizing system power.

Energy-selectivity behavior is an ability possessed by a system as the result of its generation of internal rhythmic activity which allows the system to define a range of energies it will accept, all other energies are rejected.

METHODS

Starting with the simplest configurations, inertial elements were combined into oscillators and these into various ecosystem configurations. For each model computer simulations were used to characterize response in the time and frequency domains. A unit oscillator mechanism was included as a clock mechanism in ecosystem prototypes. Potential for this kind of a mechanism was considered in competition, energy selectivity, diversity, and survival of systems. For each model, diagrams, equations, time simulations and frequency responses are given.

The following models were developed or utilized to investigate energy selectivity in biological systems:

1. a model of an electrical/mechanical oscillator;
2. a model for an autocatalytic inertial oscillator;
3. a model for an energy-selective producer;
4. models for competition between energy-selective producers;
5. a model of the Kaituna Salt Marsh -
 - a) the original model was simulated to check the normal model operational characteristics,
 - b) the model was then modified to account for the diurnal solar input,
 - c) the model was modified to incorporate an energy selective producer,
 - d) the model was modified to investigate energy selective competition.

Overall Research Procedure

Five general sections were employed to ascertain the effects of energy-selectivity on the power transfer of systems with cyclical external forcing functions.

Phase I

The first phase of this research was devoted to understanding the conceptual similarities in simple oscillator systems. Special emphasis was placed toward understanding what characteristics of these simple oscillators could be used to simulate the system rhythmic activity. Two electrical/mechanical models were tested. The electrical and mechanical models were simulated repeatedly (with any necessary modifications to the models) until the simulation results compared with known system responses. The two original choices were (a) a series approach to the production of an electrical oscillation and (b) a parallel tank circuit or bandpass approach to the production of an electrical oscillation. Ultimately, the tank circuit oscillator provided the the best opportunity for expansion into a model for the simulation of an autocatalytic inertial rhythm.

Phase II

Phase two was used to produce a phase sensing, time interpreting autocatalytic inertial oscillator (a system rhythm generator). The development of such a unit was deemed necessary because the simple addition of a linear oscillator to a producer or consumer unit within a model would provide only a rhythmic linkage and not phase adjustment or age-sequence timing. Many models for the autocatalytic inertial

oscillator were tested. However, the final oscillator model (presented in the results section) is capable of sensing source phase shifts and adjusting to those shifts. The autocatalytic inertial oscillator will allow for the adjustment of its internal rhythm and oscillator activity range (the time the oscillator will function in constant conditions); and can produce a variety of source sensing, internal, and age related timing functions.

Phase III

The third phase of this analysis was used to simulate variations of a model for a simple energy-selective producer. The model incorporated a autocatalytic inertial oscillator into a producer unit thus allowing the unit to develop an energy acceptance niche within which it could or would accept energy from one or more cyclic energy sources. The unit and load power for the producer was calculated during the simulation. The model design was based on the assumption that the producer's load (i.e. its output flow) was the unit's connection to a more complicated system.

Phase IV

Phase four was employed to simulate a number of variations for a competition model. These models simulated the competition between two energy-selective producers for the use of an external cyclic energy source. The source rhythm and the internal behavioral rhythms of the competitors were varied in successive computer simulations to analyze the effect of energy-selectivity on competition and input energy niche development. Source energy supply was also designed to investigate the effects of various combinations of source fundamental rhythms, i.e. the

addition or multiplication of two source rhythms to form one variable energy supply.

Phase V

Phase five was employed to simulate the existing Kaituna salt marsh mini-model developed by Odum, Knox, and Campbell, 1983. The model was chosen because it provided a proven mini-model with cyclic external forcing functions. The model had already been evaluated and was of reasonable proportions to enable the testing of energy-selectivity without excessive complexity. Furthermore, the model provided a reasonable framework for the analysis of energy-selective behavior within a webbed system.

Energetics Diagramming

The methodology employed to design or construct the models presented in this dissertation was developed by Alexander et al., (1980). The procedure is as follows:

- Step 1. Construct a system boundary,
- Step 2. Identify the energy flows across the system boundary,
- Step 3. Organize the system's components,
- Step 4. Connect the system components to the external sources,
- Step 5. Diagram the subsystems,
- Step 6. Evaluate or assign values to the energy model diagram,
- Step 7. Translate the energy diagram into its corresponding differential equations,
- Step 8. Simulate the model, and
- Step 9. Validate the model's response or check response to see if it meets expectations.

Identification of the System Boundary

Systems that are open exist in a hierarchy. To differentiate between the storages, flows, and sources for one system from that of another--a boundary must be defined. Boundary definition for the models employed in this research was based upon restricting complexity in model design. The concept of power utilization and transfer is complex enough without complicating the simulations with large cumbersome models. The mini-model approach to analysis requires the use of a simple model to illustrate a particular concept.

Identification of Energy Flows Across the-Boundary

Alexander et al., (1980) have developed a method for positioning energy sources around a system boundary. First, all pertinent external sources, with flows across the boundary, are identified. The source with the lowest energy quality is placed in the lower left corner of the diagram outside of the boundary. Next, the remaining sources are then placed around the boundary in a clockwise direction by increasing energy quality.

Organization of the System Components

Energy language, as developed by H.T. Odum (1976), is made up of a set of symbols, shown in Figure 5. These symbols are employed to construct energy models, and are representative of component functions which repeatedly occur in all systems.

Figure 5a is a tank or storage and is used to identify system state variables. All storages have a particular turnover time and capacity to store energy. The turnover time of a tank varies depending upon the particular pathway flow controlling the turnover. Examples of

turnover time include input turnover and output turnover. Turnover time can be found by dividing the tank storage by an input or output pathway flow. A tank with a storage of 1000 Cal and an output pathway flow of 50 Cal/hr would have a turnover time of 20 hours. The capacity of a tank is fixed and can best be described by a city water tank. The capacity for any tank is determined by its design, and for discussion let the capacity of a hypothetical city water tank be 5000 gallons. The turnover of this tank if it were half full (2500 gallons) and draining at 250 gal/hr would again be 10 hours, but the capacity would remain 5000 gallons.

Figure 5b is the symbol for an external source. This type of a source provides a constant potential which drives the flow along its associated pathway. The greater the system requirement the larger the flow.

Figure 5c is a energy sink and represents total energy degradation of a system. The energy entering the system sink is no longer usable by the system.

Figure 5d is a flow-limited source. A flow-limited source provides flow energy only. One example of a flow limited source is the solar energy provided to the earth. While this energy may increase or decrease at any given moment, the total energy supplied can never exceed the value of J , and the amount of energy available for use at any given time is J_r . The only option available to a system dependent upon this type of source (if it wants to get more energy) is to become more adapted at capturing the energy as it passes. This source differs from the previously described source because it requires the system to work harder or to become more efficient in order to obtain energy. The

source in Figure 5b is capable of supplying as large a flow as the system requires, and as a result can lead to explosive growth if not limited by some other means.

Figure 5e is a bearded tank and stores energy as a result of an acceleration, i.e. kinetic energy. The energy stored in this type of a tank is due to a change in pathway flow. The beard on the tank was derived by Odum as a result of the combination of two symbols--one from energetics and the other from electronics. The two symbols were the energy tank in Figure 5a and the electrical symbol for an inductor (see Figure 1a, in the previous section).

Figure 5f is a transformation or work gate. The interaction of two or more state variables produce a flow of energy ($k \cdot A \cdot B$). The interaction process is defined by the mathematical symbol or equation placed inside the symbol.

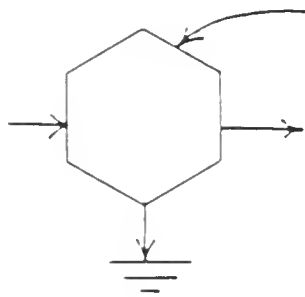
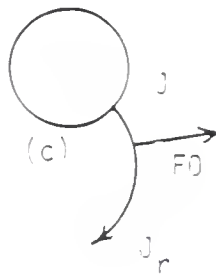
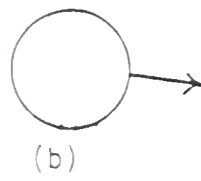
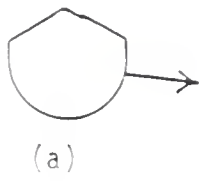
Figure 5g is a energy flow sensor. The flow of energy in pathway F1 is sensed and utilized to produce or generate some other function within the system. Photoperiodism relies on a sensor to determine the amount of light available.

Figure 5h is a group symbol for a production unit. The producer mixes low quality energy with high quality energy to produce an intermediate quality energy.

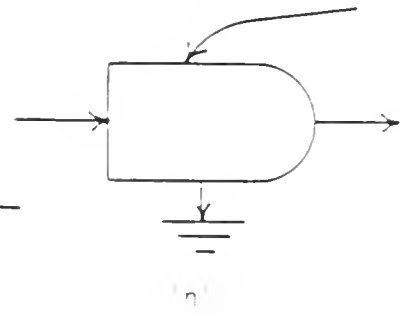
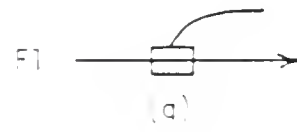
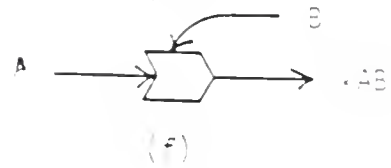
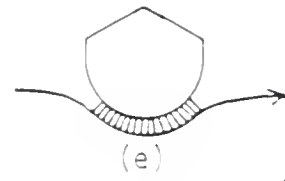
Figure 5i is another group symbol, the consumer. The consumer symbol defines a unit that is self-contained and feeds control energy back to other parts of the system.

System components are arranged within an energy circuit diagram by energy quality. Inside the system boundary the lowest quality component is located in the upper left corner of the diagram. Components with

Figure 5: Energy circuit symbols. Symbol (a) storage tank or state variable, (b) constant potential source, (c) energy sink, (d) flow limited source, (e) bearded tank which stores kinetic energy and is capable of producing inertial backforce, (f) work gate or energy transformation, (g) flow sensor, (h) producer group symbol, (i) consumer group symbol (odum, 1976 and 1983).



(i)



higher quality are then located in a descending order toward the lower left corner of the diagram.

Connection of System Components With External Sources

System components are connected to an outside source when it is determined that there exists a flow of energy from the source to the component. Solar energy to plants (producers) would constitute a pathway connection from a source of external solar energy to a producer within the system boundary.

Diagramming the Subsystems

Each group symbol represents a subsystem within the model, and is constructed in the same manner as the overall model. Each subsystem is developed by combining variations of the remaining symbols to produce subsystem functions. Mathematical notations are placed inside of the interaction symbols used in the subsystems and in the overall system to identify their specific operational characteristics.

Location of energy symbols within the subsystems is determined by their respective energy quality. The lowest quality storage is located in the upper left corner within subsystem, while the highest quality storage is located in the lower right corner within the group symbol. Interaction or transformation symbols are generally located to the right of the tank or tanks that it supplies.

Evaluation of the Energy Circuit Model

The first and second laws of thermodynamics, conservation and degradation of energy, are employed to evaluate energy circuit models. Since energy can be neither created nor destroyed, energy interactions must balance. Therefore, the energy flows entering an interaction

symbol must be equal to the energy flows leaving that symbol. The second law requires that all storages and interaction have an energy pathway to the system sink. These flows represent storage depreciation and work process losses.

Translation of the Energy Circuit Model Into its Corresponding Differential Equations

Energy circuit models can be expressed in nonlinear differential equations. For example, the model in Figure 6 contains a producer, with an autocatalytic inertial oscillator controlling the rate of the producer's biomass production. The model may be translated as follows:

$$J_r = J/(1+k_0 \cdot I)$$

$$dP/dt = k_5 \cdot J_r \cdot P / -k_6 \cdot J_r \cdot P / -k_4 \cdot P - k_3 \cdot \int P$$

$$dB/dt = k_1 \cdot J_r \cdot I - k_2 \cdot B$$

Variables (P) (K) and (B) are called "state variables" because they determine the state of the system. Constants $k_1, k_2, k_3, \dots, k_7$ do not change during simulation, and are proportionality constants of flow which determine the percent flow in their respective pathways. Flows entering a state variable are positive ($k_1 \cdot J_r \cdot I$) while flows leaving a state variable are negative ($-k_2 \cdot B$). The interaction in Figure 6 is multiplicative and is indicated as such by the "X" located in the center of the symbol.

Balancing the flows around an interaction, as required by the first law of thermodynamics, is accomplished by ensuring that each pathway equation contains the same number and type of storages and/or external sources. For example, each pathway in Figure 6 that touches the

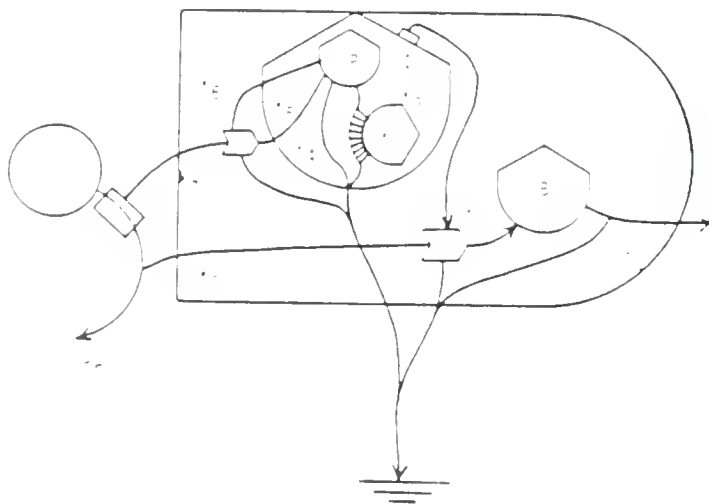
Figure 6: Model for Translation of diagram into equations. The energy circuit model is translated into the following equations:

$$J_r = J / (1 + k_0 \cdot I)$$

$$dP/dt = k_1 \cdot J_r \cdot /P/ - k_6 \cdot J_r \cdot /P/ - k_4 \cdot P - k_3 \cdot fP$$

$$dB/dt = k_1 \cdot J_r \cdot I - k_2 \cdot B$$

NOTE: The "/P/" is the absolute value of storage P



$$I_r = J_r / (1 + k_0 I_r)$$

$$dB/dt = k_1 J_r I_r - k_2 B$$

$$dP/dt = k_5 J_r I_r P_r - k_6 J_r I_r P_r - k_1 P_r - k_3 I_r P_r$$

interaction symbol has storages "Jr" and "I" in their respective equations, (see previous differential equations).

Simulation of the Model

Energetics models may be simulated with an analog or digital computer. Although the analog computer is capable of instantaneous simulation, the necessary scaling and physical setup required for a model requires a lengthy effort. Therefore, simulation of the models for this research was accomplished with a digital computer using the Continuous System Modelling Program (CSMP). The models were simulated on the Northeast Regional Data Center's main frame computers located in the Space Sciences building on the University of Florida campus, Gainesville.

The CSMP language employs "call functions" or "routines" for integration of differential equations. The program allows the selection of the integration time interval (DT) and length of time for the simulation. Example equations for the rate of change of the system state variables have already been presented. The integration of that rate of change produces the levels for the tanks in the model at any time during the simulation.

Validation of the Model

Validation of complex systems models constructed from sets of nonlinear differential equations cannot be accomplished by statistical methods. Therefore, other methods of validation must be employed. Most often models are constructed from nonlinear equations that attempt to reproduce the characteristics of the system. This approach is not without its faults. Namely, a variety of models can be produced to

reconstruct a given set of data or conditions. Construction of models with no underlying hypothesis or theory often produces models which only attempt to replicate the data and as a result significantly reduce the credibility of the model.

To avoid that problem the models constructed for this analysis have supporting hypotheses as the basis for their operation and design. The model for the autocatalytic inertial oscillator is based upon the theory that system rhythmic activity is a function of a nonlinear oscillators constructed of potential and kinetic components. Testing of the oscillator model was accomplished by analysis of existing data about the operational phenomena for system rhythmic activity. The model of the autocatalytic inertial oscillator was constructed based upon theory and not to replicate a set or sets of known data.

Models for the biological producers were constructed based upon the established energy theories and modelling design algorithms developed by H. T. Odum, 1976 and 1983. The analysis of energy-selective behavior was then tested via the simulation of these hypothetical producers. Finally energy-selective subsystems were added to an operational, evaluated, and previously simulated models of a salt marsh ecosystem. The ultimate test for these subsystems was a comparison of the model established operational characteristics vs. its new operational characteristics with the addition of energy-selective behavior.

RESULTS

Results and analyses are presented in four sections: concepts, models for biological units, models for competition between biological units, and models for a the Kaituna salt marsh, located in New Zealand. Each individual section presents the model(s), accompanying simulation plots, and applicable discussion or explanation of the results.

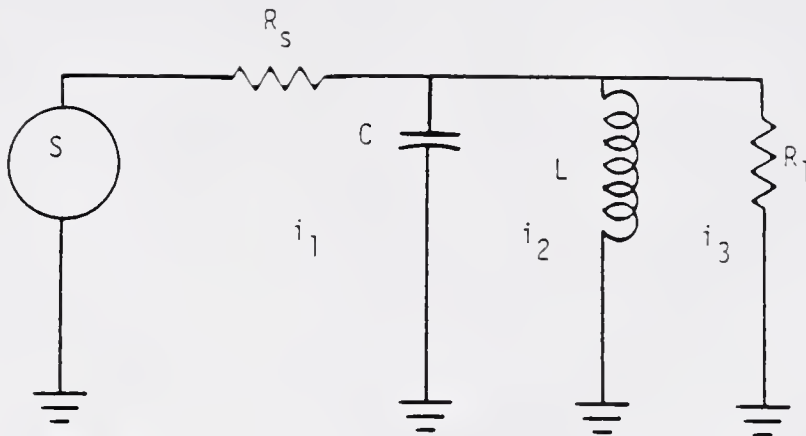
Concepts

The general concept for energy-selectivity, as a result of an intrinsic-autocatalytic-rhythmic-function, results from the extension of concepts from the electrical and mechanical inertial oscillators. Once the general principles for these simple systems had been ascertained the development of a model for the autocatalytic inertial oscillator was undertaken.

Electrical and Mechanical Oscillator Models

System components for the electrical tank circuit oscillator are shown in Figure 7a. The inertial oscillator contains a capacitor, inductor, and a source and load resistance, R_s and R_l respectively. The corresponding energy circuit diagram is shown in Figure 7b. While the electrical diagram indicates component connectivity, the system storage information for charge or potential energy in the capacitor (C), magnetic flux or kinetic energy around the inductor (L), and circuit total energy are not shown. The inadequacy of this type of diagram

Figure 7: The electrical tank circuit oscillator. Diagram a) an electrical diagram of this bandpass type of electrical oscillator, b) an energy circuit diagram for the tank oscillator. Note the indication of the storages of energy in the energy language diagram, an important aspect of this circuit which is not shown in the electrical diagram.



$$dQ/dt = 1/R_s * (S - (Q/C)) - (1/R_1 * C) * Q - 1/(L * C) * Q$$

$$i_1 = 1/R_s * (S - (Q/C))$$

$$i_2 = (1/L * C) * Q$$

$$i_3 = (1/R_1 * C) * Q$$

$$\omega = 1/(L * C)^{0.5}$$

$$\omega^2 = 1/(L * C) = 2.0 * f_o^2$$

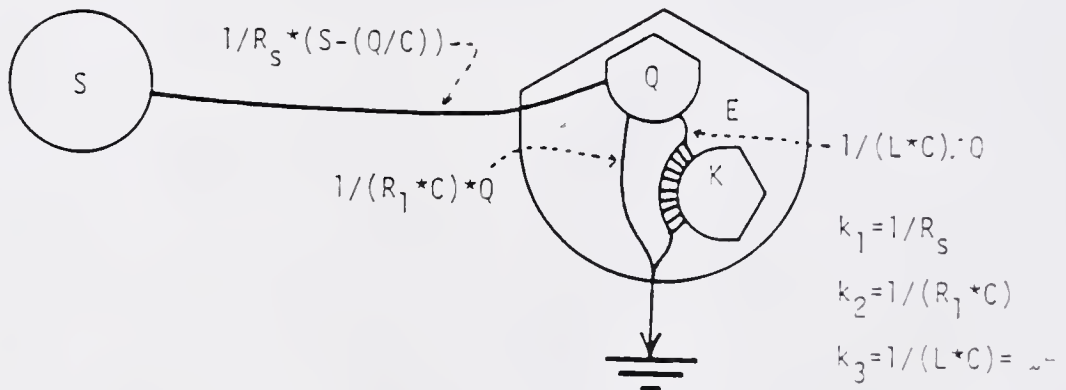
Q = storage of charge in capacitor (C)

C = capacitance (Farads)

L = inductance (Henries)

f_o = intrinsic frequency of the oscillator

(a)



$$dQ/dt = 1/R_s * (S - (Q/C)) - 1/(R_1 * C) * Q - 1/(L * C) * Q$$

$$dQ/dt = k_1 * (S - (Q/C)) - k_2 * Q - k_3 * Q$$

Energy in Q = $Q^2 / (2 * C)$ Energy in K = $(L/2) * (1/(L * C) * Q)^2 = Q^4 / (2 * L * C)$

(b)

arises from the lack of descriptiveness, i.e. the storage information is left to the reader's imagination. On the other hand, the energy circuit diagram clearly indicates component connectivity as well as the storage of energies within the system. Charge potential is stored in tank (Q) and flux kinetic energy is stored in tank (K). Total circuit energy is represented by tank (E). The beard on tank (K) indicates a back pressure effect on the flow of electrons within its supporting pathway F3 and results from magnetic field interaction with pathway electron flow.

Table 1 shows component values and flows, storage initial conditions, description, and equations for the electrical tank circuit oscillator. Table 1 also presents the equations for pathway coefficients, and coefficient values for the same oscillator. Since the model is designed to calculate its own pathway coefficients the equations shown in Table 1 are the equations within the model that calculate the flow coefficients. The initial conditions for tanks (Q), (K), and (E) are assumed to be zero. However, if tank (Q) has an initial charge then the initial conditions for tanks (K) and (E) are calculated by the model. The two equations necessary to accomplish this are shown in the table.

One interesting characteristic of these models is the integral dependency of flow F3 on tank (Q). This phenomenon results from the fact that tank (Q) provides the potential force that drives current through pathway F3, while tank (K) opposes any change in the flow of current through pathway F3. The result produces an integral dependent flow in pathway 3. The build up of magnetic flux around the inductor acts as a storage of kinetic energy, and the transfer of energy between tanks (Q) and (K) produces the system's internal oscillation.

Table 1: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Electrical Bandpass Oscillator Circuit

Component/Storage/flow	Value/Initial Condition	Name or Descriptive Comment	Equation
S	3.0	Electrical potential	$1.0 \cdot \sin(\omega \cdot t)$
R _L	1000	Load resistance	-
R _S	1000	Source resistance	-
C	1.0e-4	Electrical capacitance	-
L	2.5e-2	Electrical inductance	-
Q	0.0	Potential energy storage	$(Q^2)/(2C)$
Y	0.0	Kinetic energy storage	$(L/2) \cdot (I^2)$
I	0.0	Total energy of oscillator	$Q+K$
k ₁	1.0E-3	Coefficient flow ₁	$1/R_S$
k ₂	1.0E+1	Coefficient flow ₂	$1/R_L$
k ₃	∞	Period setting coefficient	$2 \cdot B \cdot \omega \cdot f_0$
f ₁	0.0	flow ₁	$k_1 \cdot (S - (Q/C))$
f ₂	0.0	flow ₂	$k_2 \cdot Q$
f ₃	0.0	flow ₃	k_3/Q

Note: Table for Figure 7.

Figure 8 is a plot of the electrical inertial oscillator's storages vs time. The system is driven by a source potential which also varies with time. The important conceptual characteristics shown by the plot include:

- 1) the oscillating nature of (Q) and (K) with time,
- 2) the 90 degree or $\pi/4$ radian lag of (K) to (Q),
- 3) the effect of heavy damping on the system storages as the source supply is interrupted, and
- 4) the constant amplitude of (Q) and (K) as long as source supply is available.

Figure 9a shows the mechanical inertial oscillator. Three components make up the system; they are the mass, spring, and dampers. Within this system potential energy is stored by the spring, while kinetic energy is stored by the position of the mass. The corresponding energy circuit diagram is shown in Figure 9b. As with the electrical inertial oscillator, the energy diagram more clearly indicates the storages for potential energy (X) as shown by the displacement of the system's mass, kinetic energy (K), and total energy (E). Table 2 shows the storage and flow initial conditions, component values, a descriptive comment, and the equations for the mass-spring oscillator. An intriguing characteristic of these two inertial oscillator systems is seen by a comparison of their pathway equations. Note the identical equations for system pathway coefficients, with the exception of coefficient units the system equations are exactly the same. Simply stated, the system characteristics are identical. System behavior is identical, and since the same behavioral characteristics are present in many simple inertial oscillators the behavior is repeated in other systems and may be conceptually repeated in more complex systems. One

Figure 8: Plot of the electrical oscillator system storages vs. time. Both the storage of potential and kinetic energies oscillate at a frequency determined by the pathway flow coefficient k_4 . The determination of k_4 is always $(2.0 * \pi * f)$ where:

$$\omega = 3.1415$$

f = frequency of intrinsic oscillation.

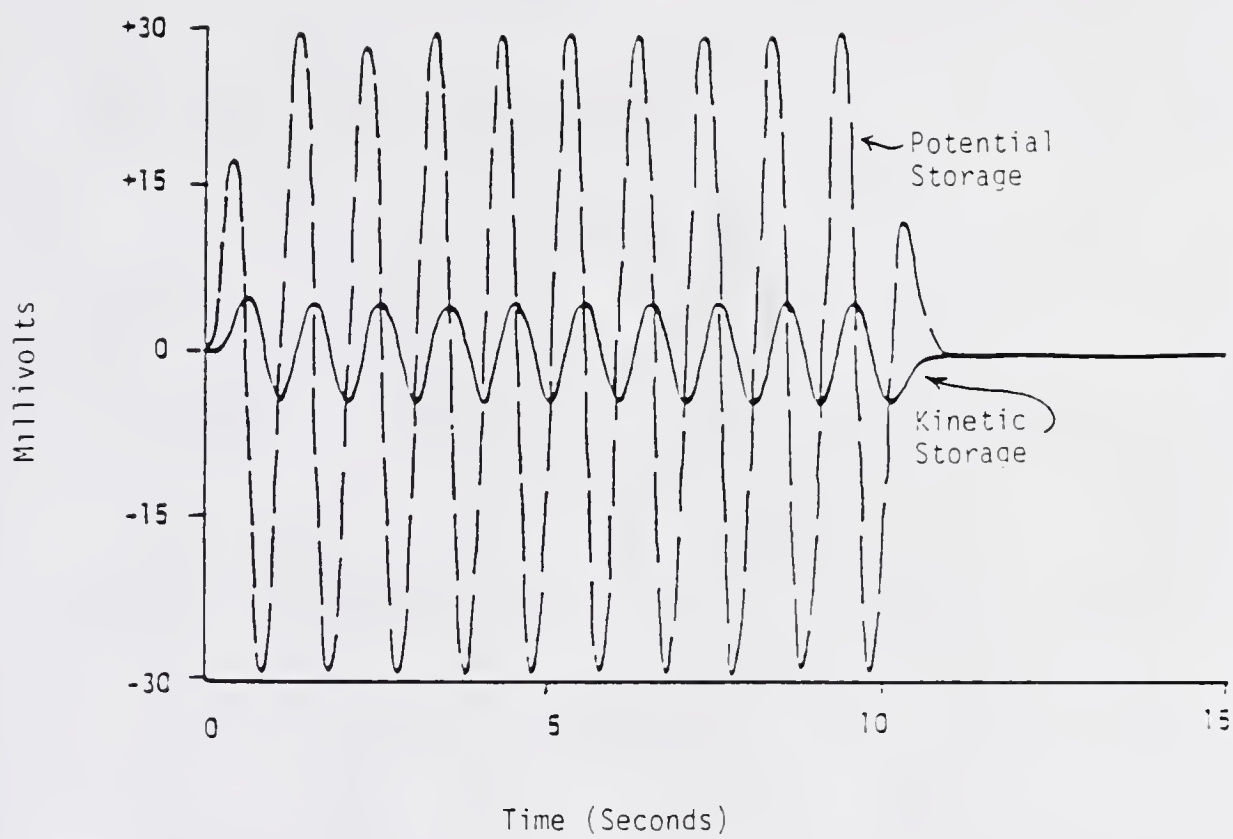
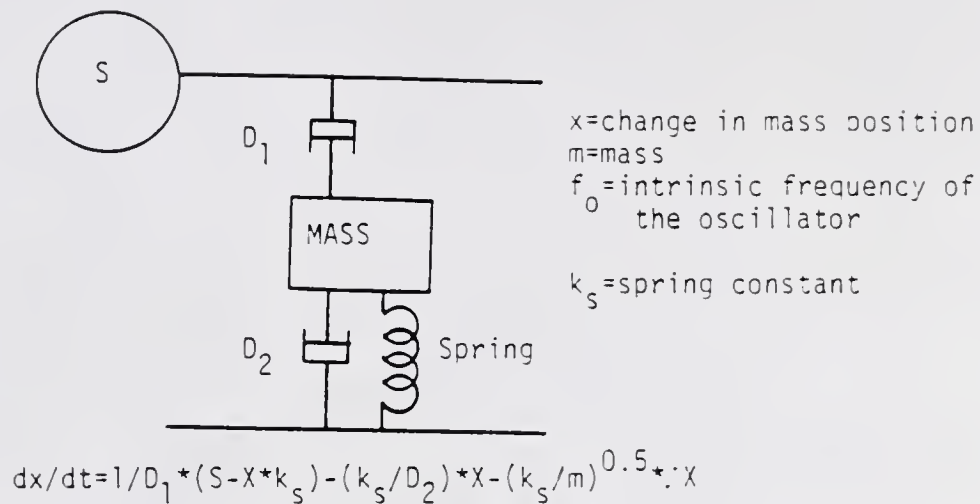
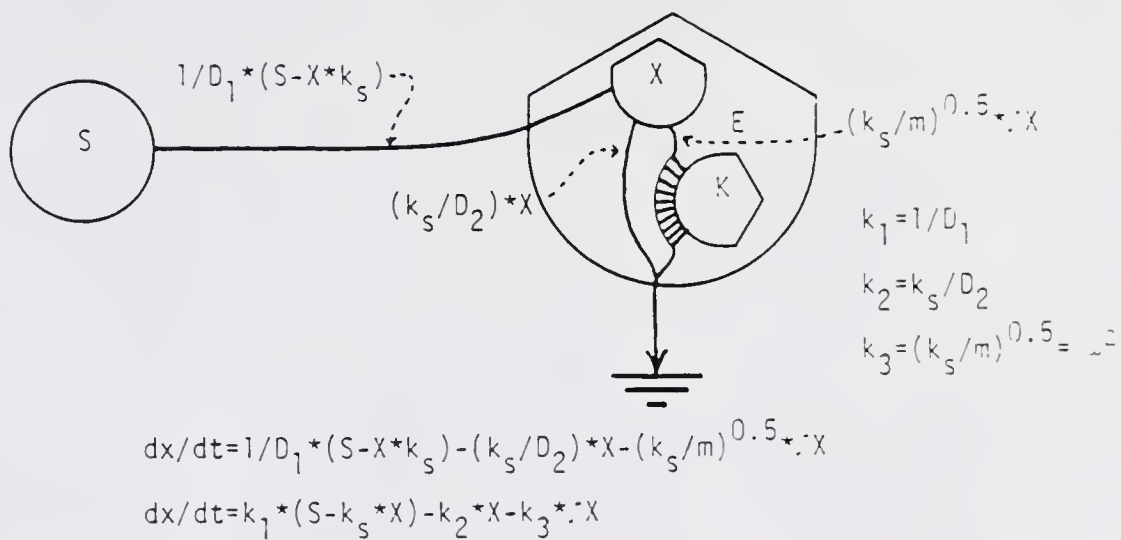


Figure 9: The mechanical mass, spring, damper oscillator. Diagram a) the mechanical diagram indicating system components and positional relationship, b) the energy circuit diagram indicating system components, energy storages, and component positional relationship.



(a)



(b)

Table 2: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Mechanical Mass-Spring Oscillator Circuit

Component/Storage/Flow	Value/Initial Condition	Name or Descriptive Comment	Equation
Source	3.0	force	$3.0 \sin(\omega \cdot t)$
B_1	1000	Damping constant 1	-
B_2	1000	Damping constant 2	-
M	250	Mass	-
k_s	1.0E+4	Spring constant	-
P	0.0	Potential energy storage	$(x^{**2})/(2 \cdot k_s)$
K	0.0	Kinetic energy storage	$(M/2) \cdot (v^{**2})$
E	0.0	Total energy of oscillator	$P+K$
f_1	1.0E-3	Coefficient flow 1	$1/B_1$
k_2	1.0E+1	Coefficient flow 2	k_s/B_2
f_3	1.0	Period setting coefficient	$2 \cdot \pi \cdot t_0$
f_1	0.0	flow 1	$k_1 \cdot (S \cdot k_s \cdot x)$
f_2	0.0	flow 2	$k_2 \cdot x$
f_3	0.0	flow 3	$k_3 \cdot x$

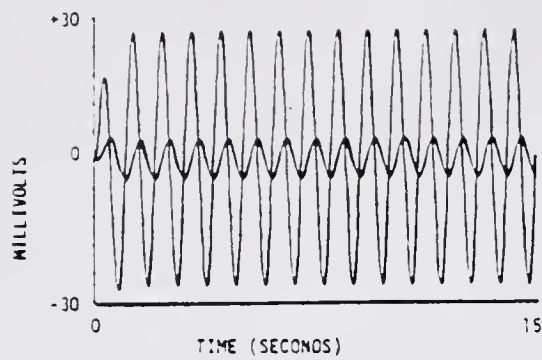
Note: Table for Figure 9.

important concept to learn from these inertial oscillators is that behavior or identical function can result from the combination of a variety of different components.

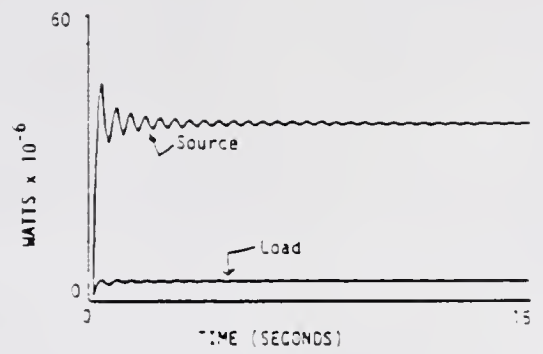
Power transfer and frequency selectivity are important concepts fundamental to understanding the operational characteristics of inertial oscillators. Power transfer (the power available to the load from the source) for both the electrical and mechanical inertial oscillators is governed by a set of identical behavioral characteristics. Figures 10a through 10f show the important power transfer characteristics of the electrical inertial oscillator. Figures 10d to 10f indicate that for the same source potential the system power is distributed differently with decreased loading. The load power, the power that is transferred from the source to the load, is maximized when the source resistance equals the load resistance (Figure 10e). When balance occurs, source power (the power lost within the source as a necessity for the transfer of energy from the source to the load) equals load power, producing a 50% transfer of power from source to load. Balance in this context describes the ratio of the load resistance to the source resistance, a perfectly balanced system occurring when the source and load resistances are equal. Figures 10a through 10c indicate that the potential energy stored within the system increases as the loading is decreased. With less energy required by the load the system is capable of storing more energy.

Figures 11a through 11f also indicate that the power available to the load is both frequency and balance dependent. Figures 11d through 11f show that the power transferred from the source to the load is maximized when the energy delivered is of the same frequency as the

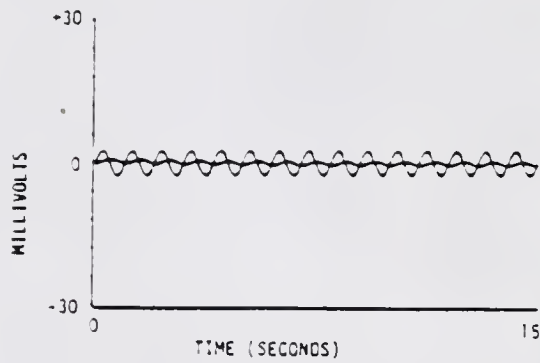
Figure 10: Resistive power transfer characteristics for the bandpass electrical oscillator. The greatest power transfer occurs when the resistance of the source equals the resistance of the load. Diagram (a) oscillator potential and kinetic storages for larger source resistance, (b) oscillator potential and kinetic storages for equal source and load resistance, (c) oscillator potential and kinetic storages for larger load resistance, (d) source and load power for larger source resistance, (e) source and load power for equal source and load resistances, (f) source and load power for larger load resistance.



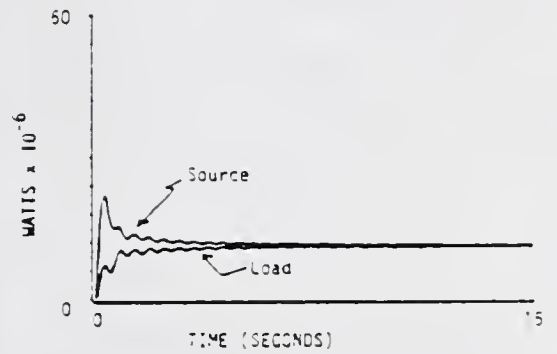
(a)



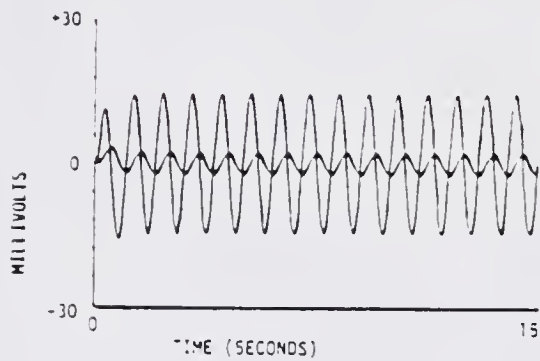
(d)



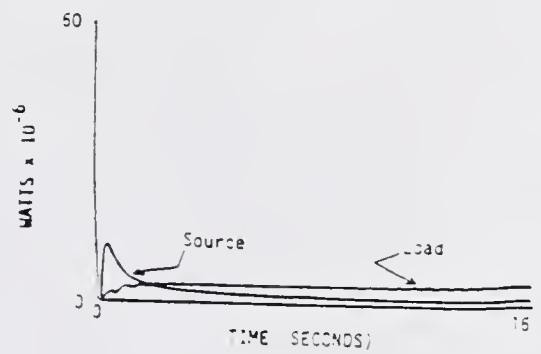
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(e)

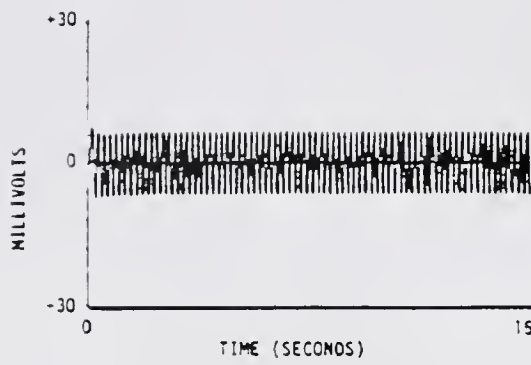


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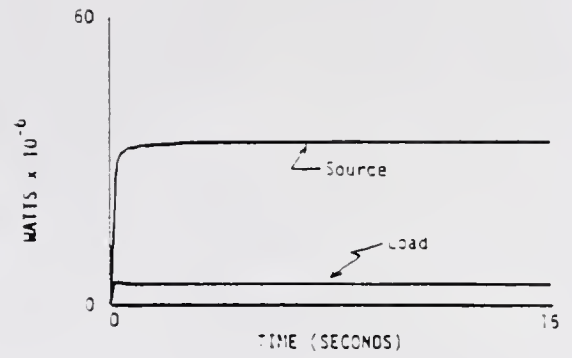


(f)

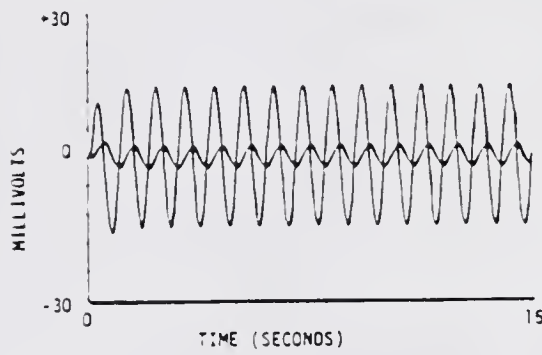
Figure 11: Frequency power characteristics for the bandpass oscillator. The greatest power transfer occurs when the frequency of the source equals the frequency of the intrinsic frequency of the oscillator. Diagram (a) oscillator potential and kinetic storages for source frequency greater than the oscillator frequency, (b) oscillator storages for source frequency equal to the oscillator frequency, (c) oscillator storages for source frequency lower than the oscillator frequency, (d) source and load power for source frequency greater than oscillator frequency, (e) source and load power for source frequency equal to oscillator frequency, (f) source and load power for source frequency lower than oscillator frequency.



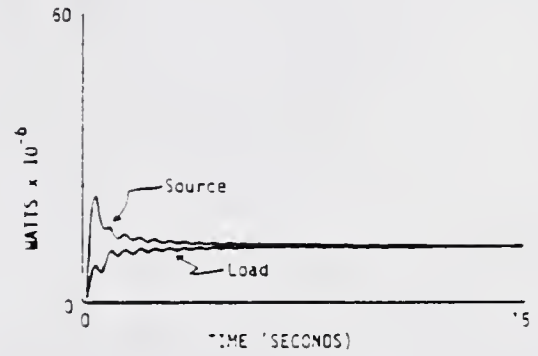
(a)



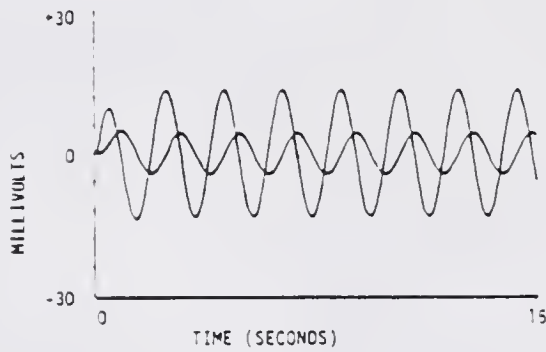
(d)



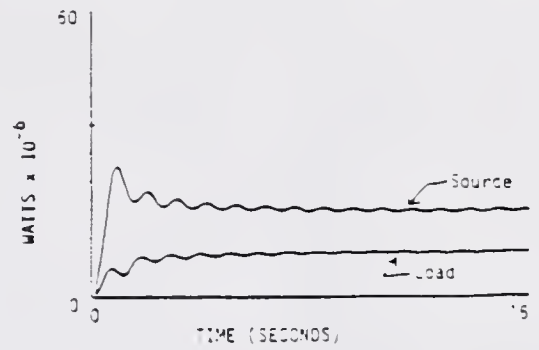
(b)



(e)



(c)

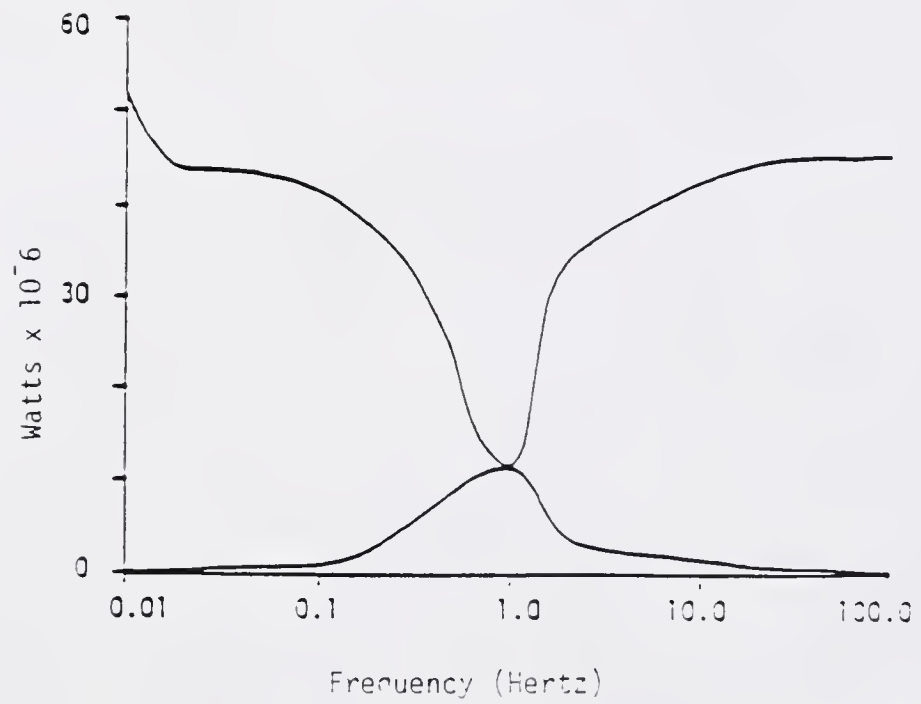


(f)

inertial oscillator's internal frequency. When the source frequency is faster or slower than the intrinsic frequency of the inertial oscillator the oscillator operates at the source frequency. Comparison of Figures 11a through 11c indicate that as the source frequency decreases, i.e. increasing period the power transferred to the load reaches a maximum when the source frequency equals the oscillator intrinsic frequency. Figures 12a and 12b summarize the results of the previous plots of load power with changing load resistance (R_l) and with changing source frequency (f_s), respectively. The greatest power transfer for changing load resistance (R_l) occurs when the source resistance (R_s) and load resistance (R_l) are equal. The greatest power transfer for changes in source frequency (f_s) occurs when the source frequency equals the inertial oscillator's intrinsic frequency (f_o). When the two frequencies are equal the system is said to be in resonance, and that particular frequency is called the resonant frequency (f_r). Moreover, at resonance the circuit operates most efficiently with the least source power lost for the most load power delivered (Figure 12b). Ultimately, the maximum power transfer from source to load occurs when the system is at resonance and is in balance. The maximum storage of energy within the system occurs when the load resistance is large (the least loading) and when the period of the source energy is long.

The same power transfer characteristics apply to the mechanical inertial oscillator, however, the components are different. Within the mechanical oscillator maximum power transfer occurs when the damping of the source equals the damping of the load, and when the system oscillation equals the source oscillation. Regardless of the system (electrical or mechanical) the behavior for both systems is the same.

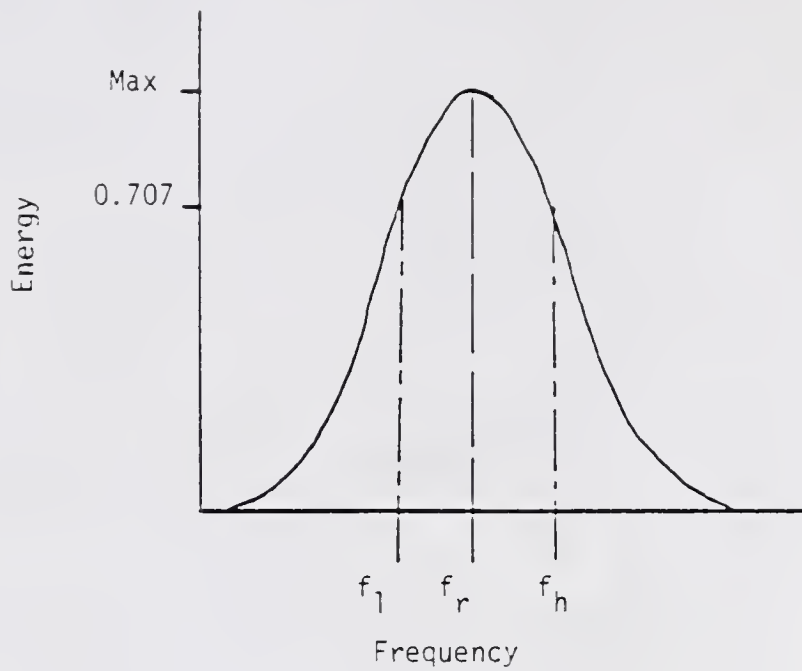
Figure 12: Summary of power characteristics for the bandpass oscillator. Plot (a) source and load power with changing load resistance, (b) source and load power with changing source frequency. The greatest power transfer occurs when source and load resistance and frequency are equal.



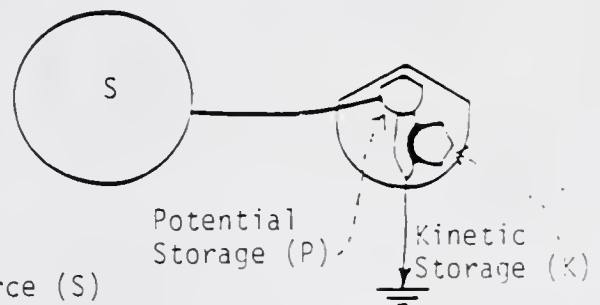
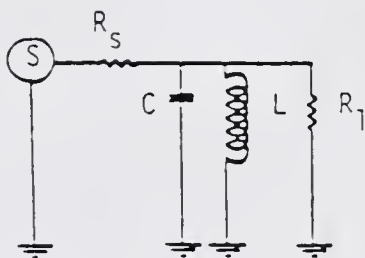
The preceding paragraphs and figures have presented the concepts for power transfer and energy selectivity with a limited reliance upon mathematics. However, the electrical inertial oscillator lends itself readily to a mathematical presentation of these concepts. Figure 13 again shows the electrical and energy circuit diagrams for the tank oscillator (often called a bandpass oscillator because of its property of passing only a range of frequencies to the load). Equations 1 through 11 show the mathematical relationships for the system, in both languages. The range of frequencies that are passed to the load is often limited, for practical use, to a specific subset of frequencies called the circuit bandwidth. The bandwidth depends solely upon the load resistance (R_l), the inductor's (L) value, and a constant equal to $2.0 \cdot \pi$. Useful power transfer occurs for frequencies that deliver potentials greater than or equal to 70.7% of the source potential (Ekeland, 1981). The frequencies that deliver these potentials are within the bandwidth of the inertial oscillator circuit. The high and low cutoff frequencies for the bandwidth are calculated from the values of the system components. Equations 1 and 8 describe the calculations necessary to determine the bandwidth of the circuit shown in Figure 13. The accompanying equations 4 and 11 indicate the relationship of circuit components necessary to calculate resonant frequency. Resonant frequency for an inertial oscillator defines the center of its bandwidth because it is the frequency that transfers the most energy and power.

The concept of maximum power transfer as a result of energy selectivity is established for the electrical and mechanical oscillators. The previous paragraphs and figures describe the general characteristics of this phenomenon. The following sections describe the

Figure 13: The diagram shows the mathematical relationships for the bandwidth of the electrical oscillator. Diagram a) the electrical circuit and corresponding equations, b) the energy circuit and corresponding equations. The equations describe the same bandwidth because the two diagrams are mathematically identical. The advantage of the energy diagram is the clarity of presentation for components and storages not as clearly indicated by the electrical diagram.



(a)



Note: Consider R_s part of source (S)

$$BW = R_1 / (2.0 \pi L)$$

$$f_l = f_r - (BW/2)$$

$$f_h = f_r + (BW/2)$$

$$f_r = (1/2) \pi (L \cdot C)^{0.5}$$

$$k_2 = 1 / (R_1 \cdot C)$$

$$k_3 = 1 / (L \cdot C) = \omega_0^2$$

$$k_3 / k_2 = R_1 / L$$

$$BW = k_3 / (2 \pi k_2) = R_1 / (2 \pi L)$$

$$f_l = f_r - (BW/2)$$

$$f_h = f_r + (BW/2)$$

$$f_r = k_3^{0.5} / (2 \pi)$$

(b)

extension of these concepts into the development of a autocatalytic oscillator, and through the use of the biological oscillator present the concept of energy selectivity for biological systems.

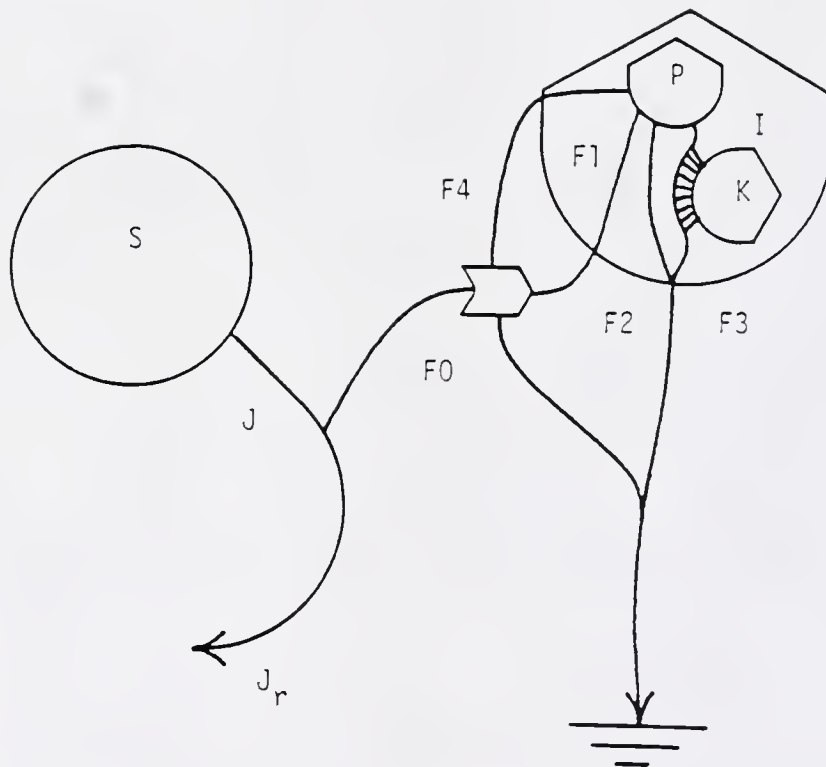
Autocatalytic Inertial Oscillator Model

Electrical and mechanical inertial oscillators exhibit some of the important characteristics required for biological rhythmic behavior, however they do not self-adjust nor do they exhibit growth with time. They do possess an internal timing between their potential (P) and kinetic (K) components, and exhibit time relationships between their internal components and an external source. While these qualities are necessary for biological oscillators they fall far short of the complexity generated by the addition of nonlinear autocatalytic behavior within the inertial oscillator itself.

The autocatalytic inertial oscillator incorporates a non-linear internal feedback within the oscillator, and as a result, produces a phase adjusting oscillator capable of sensing environmental sources and remaining tuned to those sources. Timing functions within the autocatalytic inertial oscillator also grow with time and might therefore be utilized to initiate action with increased age.

Figure 14 is an energy circuit diagram of the autocatalytic inertial oscillator developed for this study. Equations 1 and 2 present the mathematical relationship of the inertial oscillator system components. The // indicates the use of the absolute value, and is necessary because the energy flows within the inertial oscillator are capable of completely reversing their directional flow. Environmental sources normally have some constant energy about which the available energy varies. However, the inertial oscillator senses rhythmic change

Figure 14: The autocatalytic clock. Intrinsic rhythm is made self-adjusting by the addition of internal feedback. Furthermore, the growth with time of the potential and kinetic energy storages might provide an explanation for clock-initiated age functions i.e. reproductive behavior. Timing initiators also include nocturnal activity, seasonal timed activity, and environmentally sensed initiation of particular processes i.e. flowering and fruiting.



$$\frac{dP}{dt} = k_1 \cdot J_r \cdot P / -k_4 \cdot J_r \cdot P / -k_2 \cdot P - k_3 \cdot \omega \cdot P$$

$$J_r = J / (1 + k_0 \cdot P /)$$

$$S = A \cdot \sin(\omega_s \cdot t)$$

$$k_3 = \text{Frequency setting coefficient} = \omega_0^2$$

$$\omega_0 = 2 \cdot \pi \cdot f_i$$

f = oscillator's intrinsic frequency

and as a result the // is required to ensure that flow directions within the inertial oscillator remain in proper phase relationship.

Autocatalytic inertial oscillator timing functions include five useful timing initiators. First, the summation of potential and kinetic energies within the inertial oscillator can be utilized as a product in an energy transformation or work gate function. Figure 15 is an energy diagram depicting an autocatalytic inertial oscillator as part of a energy transformation or work function. The system is energy-selective as a result of producer's inertial oscillator activity, and this particular concept is presented by simulation plots in the next section. The model is provided to familiarize the reader with the location of components in an energy-selective production module. Source energy to the system is flow limited, and the system has a recycle of (B) through (N). Flow F2 indicates that the recycle of nutrients requires some energy loss from the pathway. Figure 16 shows the concept for the second timing initiator. The timing of the potential and kinetic tanks (P) and/or (K) might be utilized as time indicators or process function initiators. For example, the hunting initiator for nocturnal predators or the tidal feeding initiator for clams, oysters, and/or mussels. For the third timer, the timing combination of tanks (P) and (K) combine with an ability to sense a source rhythm to begin or initiate process functions. Examples of this characteristic could be the flowering of plants or the thickening of animal furs during winter. Figure 17 is a model depicting the concept of timing with a source and internal inertial oscillator combination as the timer. Fourth, the amplitude of tanks (P) and/or (K) are employed to initiate some age process or function. One example, for this type of inertial oscillator activity

Figure 15: Autocatalytic clock as part of a workgate. The system uses energy selectivity to acquire input energy and to generate biomass. The diagram and following plots are presented only to familiarize the reader with the use of the autocatalytic clock.

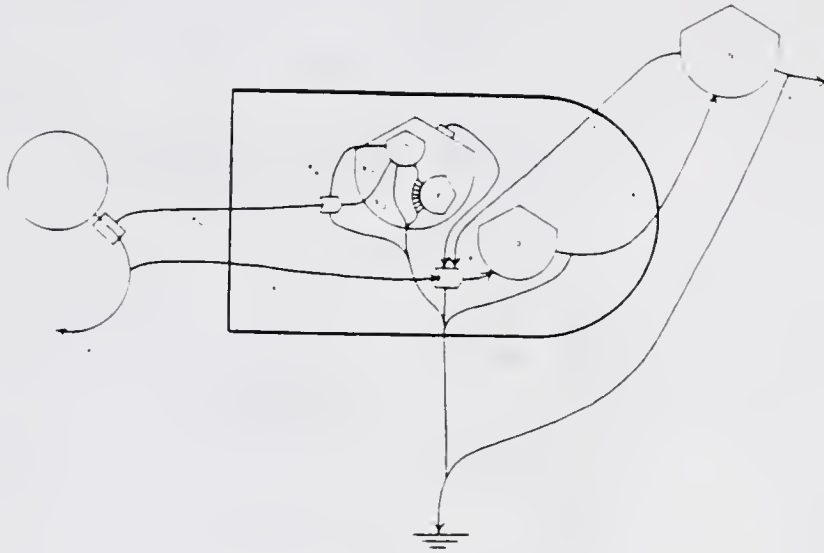


Figure 16: Timing initiator for potential component of the autocatalytic clock. This particular timing initiator might be employed by a biological unit to initiate nocturnal activity.

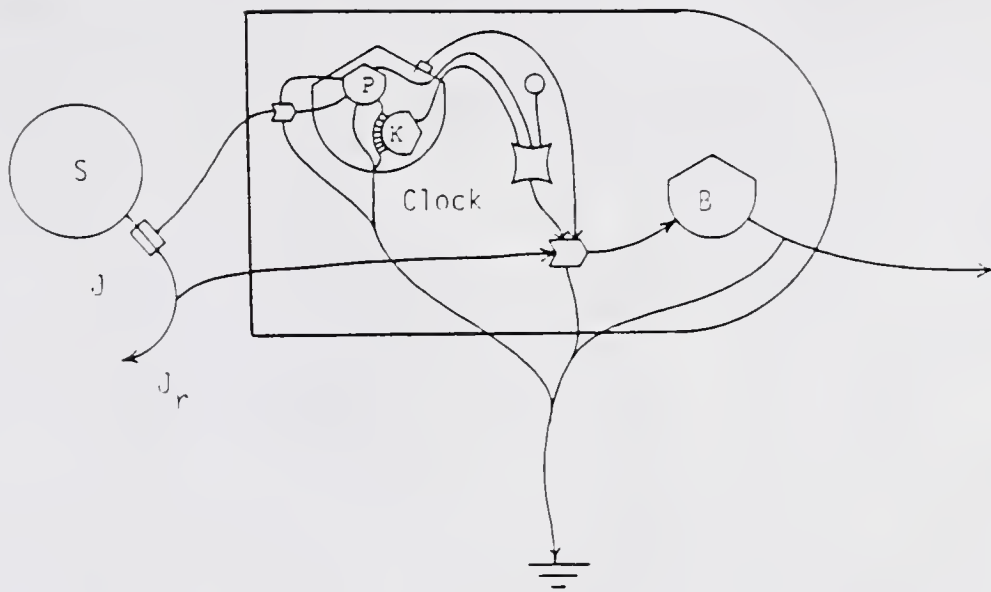
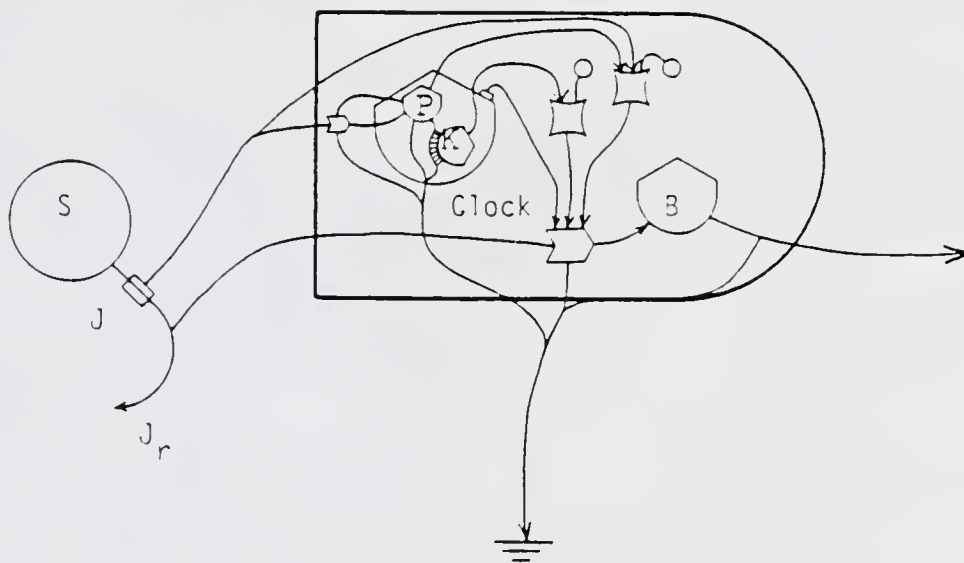


Figure 17: Biological timing using the source rhythm as well as both the potential and kinetic components of the autocatalytic clock.



might be the initiation of a particular reproductive behavior which results from the autocatalytic growth of tank (P) and/or (K). When one or both of the tanks reach a predetermined level, the autocatalytic inertial oscillator could initiate the production of hormones that in turn produce timed reproductive behavior. Figure 18 is a model for the age process initiator of the autocatalytic inertial oscillator. The fifth timer results from the combination of some or all of the previous functions and could be utilized to simulate complex forms of behavior. The model shown in Figure 19 uses all the previous timing functions to produce a complex timing behavior capable of timing both diurnal as well as annual rhythms within the environment and produces autocatalytic inertial oscillator behavior that can take advantage of that knowledge.

Autocatalytic inertial oscillator phasing with an external source plays an important role in the behavior of an individual system within a given environment. Therefore, the phase relationship of the potential (P) and kinetic (K) of the inertial oscillator in relation to the source is important. If an individual biological system is to remain in tune with its environment it must adapt to changes in source phasing.

Phase-shift experiments are employed to test the self-phasing of biological systems. These experiments substitute laboratory phase-shifted signals for normal environmental rhythms and examine the effects of the new false signal on the system. As an example, Webb (1950) studied a group of fiddler crabs (Uca) to analyze phase shifting in the crab's color-rhythms. Webb substituted darkness during normal light, and light during normal darkness producing a 12-hour phase change in the crab's color-rhythm. The crabs subjected to the phase-shifted-

Figure 18: Biological timing as a result of the amplitude of autocatalytic clock rhythms. This timing might be used for reproductive behavior. The timing is a response to the age of the biological unit.

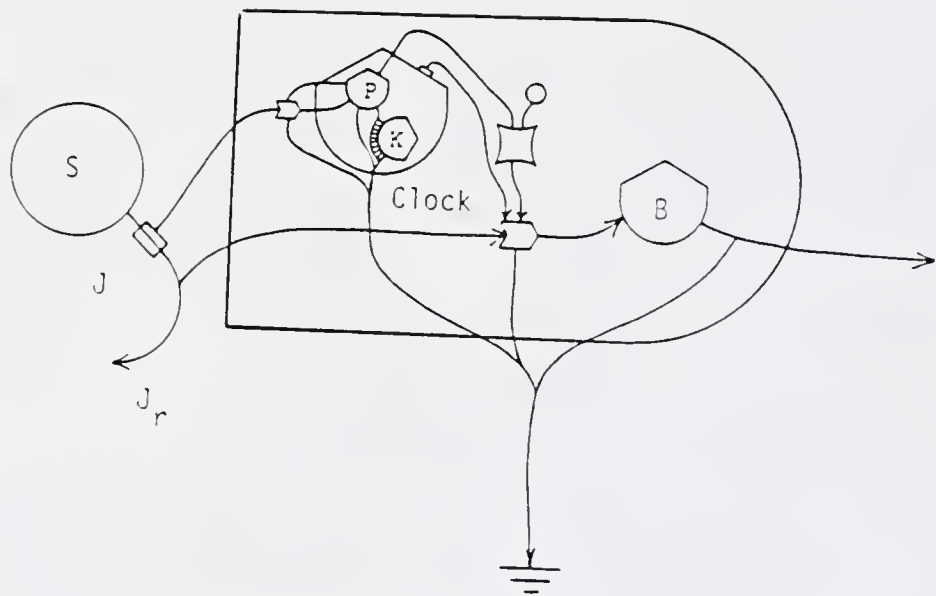
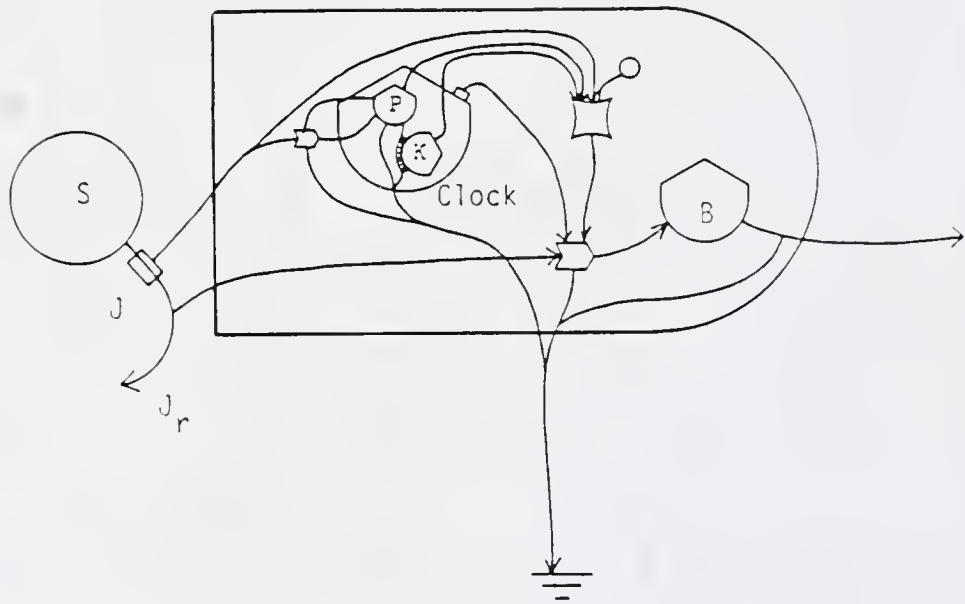


Figure 19: Biological timing as a combination of the four previous timing initiators. This type of timing produces complex behavior by timing the environment as well as the individual timing characteristics of the unit's autocatalytic clock.

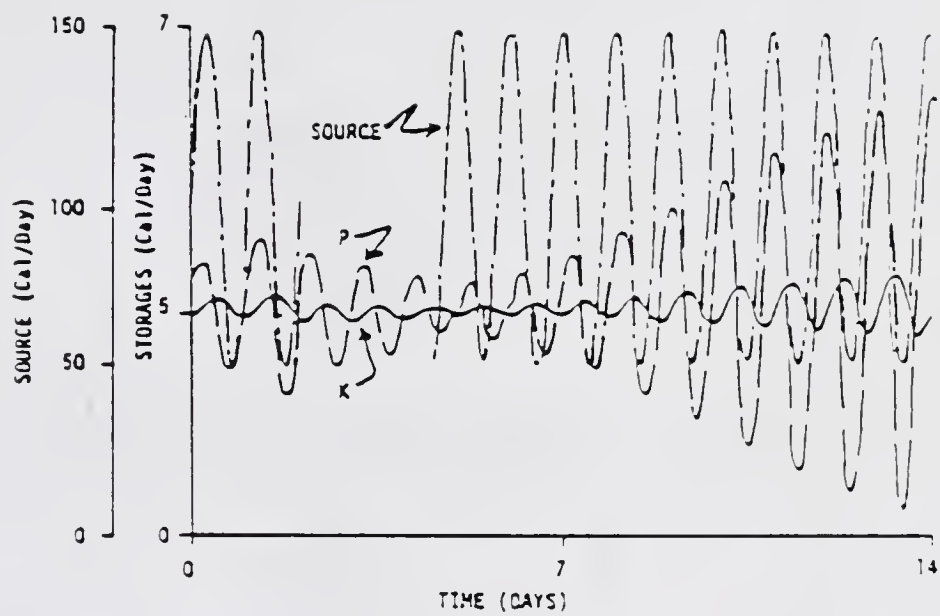


signal altered their intrinsic rhythms to self-align with the new (albeit false) environmental signal. Therefore, any model of a biological rhythm generator must be able to self-phase with its environmental.

Figure 20 is a plot showing the autocatalytic inertial oscillator's ability to self-phase when presented with a phase-shifted external signal. The simulation begins with a source supply that is sine-phased. The autocatalytic inertial oscillator is in tune with the source, and storages (P) and (K) are increasing and in normal phase relation. Between time 2.0 and 4.5 the source rhythm is eliminated. The inertial oscillator oscillation continues with the same phasing, however, the levels in tanks (P) and (K) decrease. This decrease is the result of depreciation losses via pathway F2, and is required by the second law of thermodynamics. Beginning at time 4.5 the source is reinstated with an cosine-phased oscillation i.e. a 90 degree or $\pi/4$ radian shift from the original source rhythm. Oscillator potential (P) and kinetic (K) components experience a significant perturbation within the next two cycles, after which time the autocatalytic inertial oscillator self-tunes to the source's new phasing. Within the next seven cycles the inertial oscillator completely re-establishes an in-phase relationship with the source.

Frequency setting and damping of internal rhythms also play an important role in an system's ability to maintain rhythmic behavior or to efficiently utilize its internal rhythmic activity in a competitive situation. The frequency setting coefficient k_3 (in the model shown in Figure 14) is always equal to $\frac{\omega^2}{2}$. In radian units is $2.0 * \pi * f_0$, where (f_0) is the intrinsic frequency of the inertial oscillator.

Figure 20: Plot indicating the ability of the autocatalytic clock to self-adjust to changes in phase of an environmental source. The damping during source elimination results from a second law loss of energy via pathway F3, and is a requirement for all systems--including internal clocks. Full recovery as a result of the phase shift introduced into the source required seven oscillations or periods.



Coefficient k_3 is extremely important to the operation of the autocatalytic inertial oscillator because it controls the period of the autocatalytic inertial oscillator's internal oscillation. The exact method by which biological oscillators set their rhythms is still not clearly understood, however the ability to identify these periods of biological rhythms does exist. The periods for intrinsic rhythms are known for many plants and animals. Within humans internal free running biological rhythms exhibit a period range from 19 hours to 25.8 hours and were identified from cave and bunker studies (Palmer, 1976). The following passage is an example of how biological system intrinsic rhythms may be identified.

Over a decade ago, a young speleologist became obsessed with the idea that it was scientifically important for him to live alone, underground, sans clocks, for two months. He chose an inhospitable cave in the French Alps where he lived at the 375-foot level. Here the temperature hovered at 32 degrees (F), the relative humidity remained unchanged at 100%, and the darkness was complete save for a small battery-powered light in his tent. Each time he awoke, ate, or prepared to retire he called over a field telephone to a surface camp, where his lonely words and the times of his calls were recorded. He claimed that the inexorable cold and dampness reduced his body temperature to less than 97 degrees (F), and he was constantly threatened by avalanches and cave-ins --- still, he held out for the sake of science and whiled away his time writing a best-selling novel about his subterranean adventures, anxiety, and building libido.

Throughout his underground stay, he tried mentally to keep track of the passage of time on the surface. When the men in the surface camp informed him on September 14 that his experiment was over, he thought it was only August 20. His subjective judgement of the passage of time had been exceedingly sluggish; mentally, he had lost 25 days! A major problem in his estimation of the passage of time was the fact that he commonly imagined that he was taking a short siesta after his midday meal, where in reality he had been awake for 16+ hours and

his "nap" lasted approximately 8 hours. However, his living clock, as evaluated by the times of his retiring and awaking phone calls to the surface, had ignored his mental confusion and guided his body functions all the while, measuring off periods of activity and sleep that total just longer than a day: 24 hours and 30 minutes on average (Palmer, 1976 p. 125).

The above passage illustrates the intrinsic rhythm setting and damping properties of internal biological rhythm generators (living clocks as described by Palmer). The frequency of biological oscillators is determined under constant conditions, and many experiments are directed solely at determining these rhythms. Interestingly, one way to find the intrinsic rhythm of an electrical or mechanical inertial oscillator is to remove the oscillator from its energy supply and time the period of its intrinsic oscillation.

The duration of oscillator activity, the amount of time an autocatalytic inertial oscillator rhythm remains active when isolated from its energy cue by placing it into constant conditions is also important. The ability of a biological system to adapt to interruptions in energy supply is critical. With heavy damping an autocatalytic inertial oscillator loses its rhythm (in constant conditions) within a short period of time. However, with light damping the autocatalytic inertial oscillator could maintain a rhythmic pattern for long periods of time--as in the above passage for two months or longer. Damping determines the longevity of the autocatalytic inertial oscillator's activity when environmental conditions become constant. One example of an interruption in an environmental source supply is a drought in a normally wet area.

With these characteristics in mind, the simulation of biological rhythmic activity by an autocatalytic inertial oscillator requires that

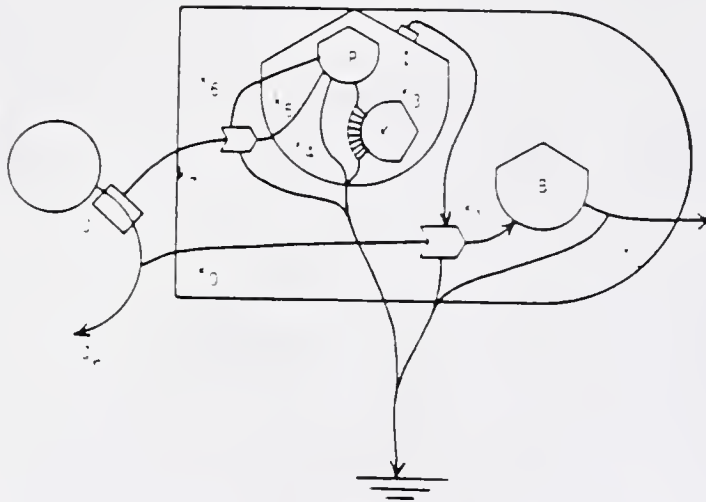
the internal autocatalytic inertial oscillator characteristics be adjustable. Coefficients k_3 and k_2 satisfy these requirements. Pathway coefficient k_3 , sets the intrinsic rhythm, while coefficient k_2 adjusts the damping. Damping of the autocatalytic inertial oscillator's free-running rhythm is the direct result of the depreciation losses within the inertial oscillator, and in the model is accounted for by pathway F2.

Biological Models with Autocatalytic Inertial Oscillators

The previous section presented results for the energy circuit autocatalytic inertial oscillator. Development of this oscillator is an important initial step in the analysis of energy selectivity and its effect on the power maximization and power transfer within biological systems. The following model, plots, and figures illustrate the effect of energy selectivity on power transfer and biomass generation for a producer with an internal autocatalytic inertial oscillator. The model is intended to illustrate the effects of energy selectivity on a hypothetical biological system.

Figure 21 is an energy diagram for an energy-selective producer. Table 3 presents the storage initial conditions, the pathway coefficients, a descriptive comment, and the equations for the model in Figure 21. The production of biomass (pathway F1) is regulated by the activity of the producer's internal autocatalytic inertial oscillator. Since the autocatalytic inertial oscillator is energy selective, the work gate or energy transformation function is also energy-selective. Pathway F2 is the autocatalytic inertial oscillator's sensor and provides information to the inertial oscillator about the rhythmic changes that occur in its environment. Pathways F6 and F7 are

Figure 21: Energy diagram for an energy-selective producer. The clock produces an internal rhythm required for the production of unit biomass. Equations 1 through 4 describe the component relationships in mathematical language.



$$J_r = J / (1 + k_0 I)$$

$$dB/dt = k_1 J_r I - k_2 B$$

$$dP/dt = k_5 J_r / P - k_6 J_r / P - k_4 P - k_3 \cdot P$$

Table 3: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Model of the Energy Selective Producer

Storage/flow/component	Value	Name or Description	Equation
Biomass			
Clock			
P	$1.0E+6$	Biomass of producer	$k_1^*I^*Jr \cdot k_3^*B$
E	0.0	Energy stored in clock	$P \cdot t$
E_0	$1.0E+5$	Potential energy in clock	$(P \cdot 10^{**2}) / (2^*C)$
E_1	0.0	Kinetic energy in clock	$(1/2) * (E_3^{**2})$
E_2	$3.7E+5$	Solar energy to producer	$k_0^*I^*Jr$
E_3	$3.0E+4$	Biomass production	$k_1^*I^*Jr$
E_4	$3.7E+5$	Solar energy sensor	$k_2^*P^*Jr$
E_5	$3.0E+4$	Biomass export	k_3^*B
E_6	$6.0E+4$	Input of sensor to clock	$k_4^*P^*Jr$
E_7	$3.0E+4$	Autocatalytic feedback of clock potential to sensor	$k_5^*P^*Jr$
E_8	$5.0E+3$	Depreciation of clock potential	k_6^*P
E_9	$5.0E+3$	Depreciation of clock potential with inertial backforce	k_7^*P
E_{10}	$1.0E+4$	Potential capacity of clock	
E_{11}	0.0	Period setting coefficient	$2.0E+*10$

Note: Table for Figure 21.

depreciation pathways. A linear depreciation is provided for by pathway F6 and represents the normal depreciation losses within the inertial oscillator. These losses include physical losses such as cellular breakdown. Pathway F7 represents the depreciation losses experienced by the autocatalytic inertial oscillator however these loss are opposed by a kinetic inertial backpressure. Kinetic inertial backpressure is felt as a byproduct of the flow in pathway F7.

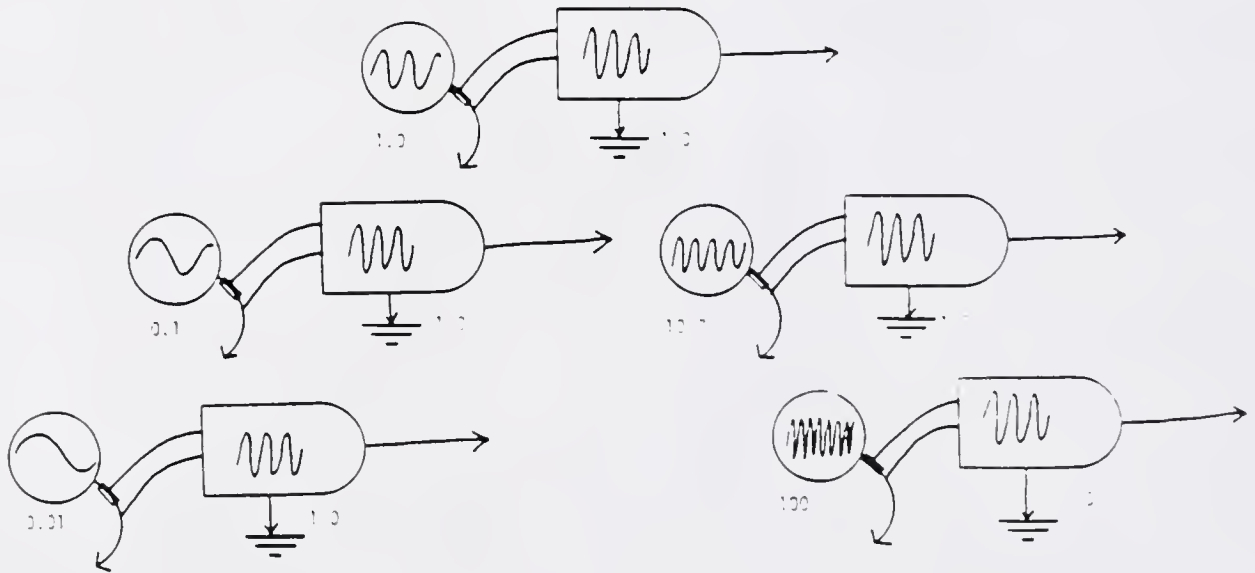
The total energy of the autocatalytic inertial oscillator is the sum of the inertial oscillator's potential and kinetic energies, and is employed as the work gate regulator. When the source rhythm is outside of the producer's range of energy acceptance the producer rejects the available energy and production of biomass decreases.

An energy-selective producer increases its biomass or net production within a defined range of energies, i.e. a biological energy acceptance niche. The term bandwidth is used to describe the energy acceptance range for the electrical and mechanical inertial oscillators. The analogy for bandwidth in ecological systems is NICHE. Figure 22a shows an energy acceptance niche for a producer with a free-running internal biological inertial rhythm having a 24 hour period of oscillation. The width of an energy-acceptance niche could be employed to determine whether the producer is a specialist or simple generalist. The models in Figure 22b show the relative frequency relationships for the simulations employed to produce the energy-acceptance niche in the Figure 22a. The source rhythms are depicted in the circular source symbols while the producers' intrinsic rhythms are depicted in the bullet symbols used for energy circuit producers. The figure clearly indicates that the most biomass is generated when the source and producer rhythms are equal.

Figure 22: Plot indicating the niche width of an energy selective producer with an intrinsic rhythm of one day. The niche might be called an energy acceptance niche since it defines the range of frequencies or rhythms within which the producer accepts energy input. This figure was produced by plotting the steady state biomass for five simulations of the model in figure 21. For each simulation the internal rhythm of the producer was held constant at 1 period per day, while the source rhythm was varied during the simulations. The source periods ranged from 0.01 to 100 oscillations per day. The mini-diagrams in (b) are only to aid in distinguishing between the relative period changes. Since the change in source period varied by order of several magnitudes plotting these rhythms for presentation was impractical.



(a)



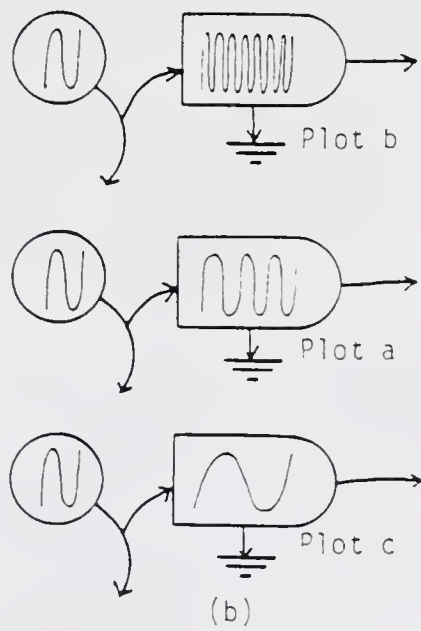
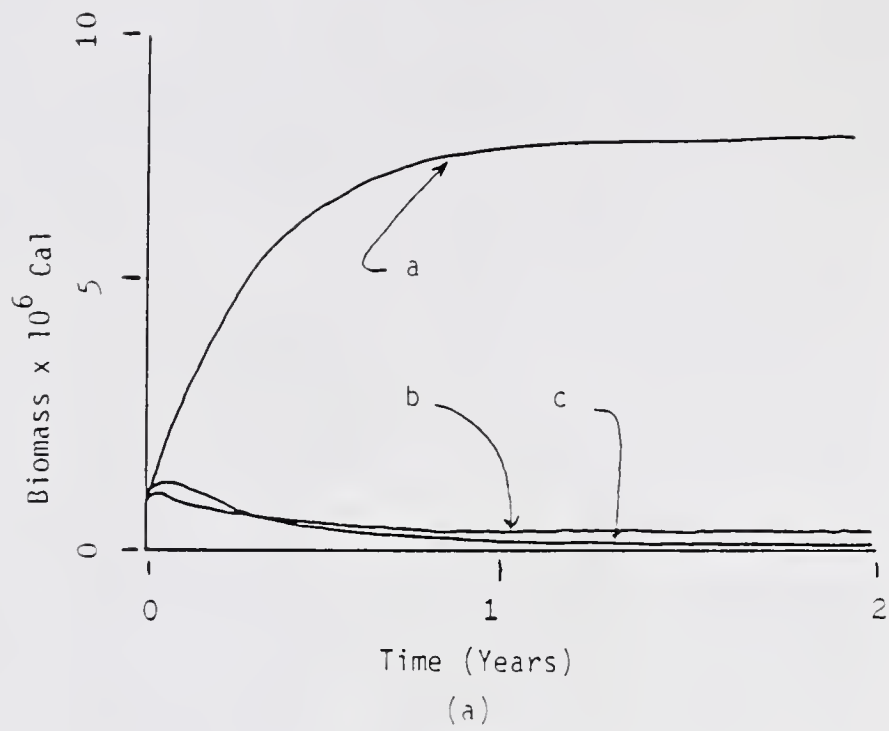
(b)

Energy Selective Biomass Generation

This section shows the results of the analysis for the energy-selective generation of biomass. The producer simulations show that energy transfer for the generation of producer biomass occurs at the frequencies within the energy-acceptance niche of the producer. Frequencies outside of the producer's energy-acceptance niche generate no biomass.

The plots in Figure 23a show the effect of energy-selectivity on a producer's biomass for source energies less than, equal to, and greater than the producer's intrinsic rhythm. The plots clearly show the producer's capability for accepting or rejecting rhythmic energies. Biomass attains its greatest level when the producer's free-running autocatalytic inertial oscillation equals the frequency of the available energy (plot line a). When the available source energy oscillates with a rhythm outside of the producer's acceptance range the producer rejects the energy (plot lines b and c). Figure 23b shows the producer's internal autocatalytic inertial oscillator generates a rhythmic behavior within the producer that is either in or out of step with the source rhythm, thereby selectively accepting or rejecting the opportunity to utilize available energy. The three mini-models show the relative period relationships for the source and intrinsic producer rhythms. Whether the former or the latter is true, the producer by its autocatalytic oscillator-regulated activity defines its acceptance niche within which it accepts energy. Interestingly, biomass generation about the producer's fundamental rhythm appears relatively symmetrical.

Figure 23: Simulation plots and relative frequency diagram for the energy-selective producer in Figure 21. Plot line (a) shows the growth in producer biomass for source energy inside the producer's energy-acceptance niche. Plot lines (b) and (c) show the decrease in biomass for source energies at frequencies outside of the producer's energy-acceptance niche. The greatest biomass generation occurs for supply energy at the free-running rhythm of the producer's intrinsic rhythm.



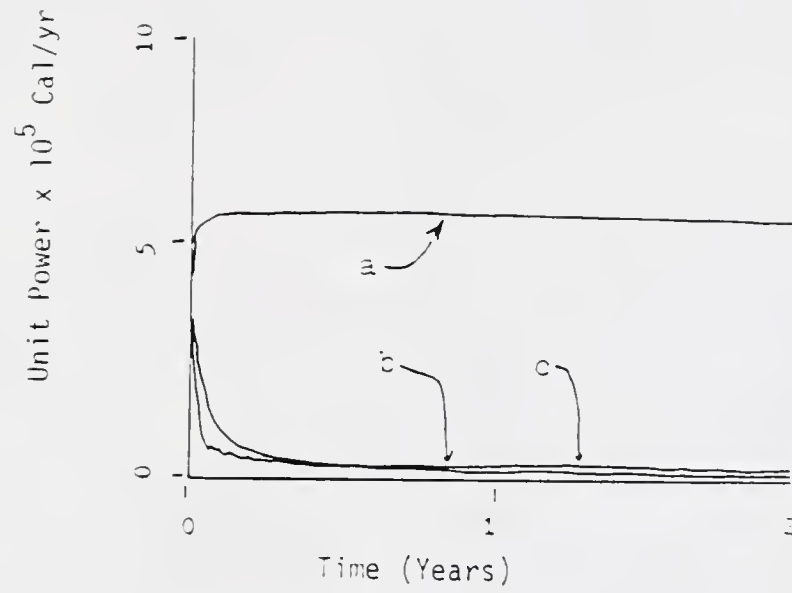
Power Transfer for an Energy Selective Producer

Figures 24a and 24b show the producer's unit power and power transfer for the three plots in Figure 23. The maximum power transferred by the producer to the remainder of the system (via F3) occurs when the rhythms of the producer and the system are matched. For all source rhythms outside the producer's energy-acceptance niche power and energy are rejected and power transfer is minimized. Producers that develop acceptance niches too far removed from their environmental signals do not possess the ability to pass on an appreciable amount of power from an external source to the remainder of the system. A producer capable of attracting more energy and power and transferring more power to the next component in a system is also contributing more toward the power maximization of the system as a whole. This concept plays an important role in the "Maximization of Power" as introduced by Lotka, 1922 and later refined by Odum, 1976.

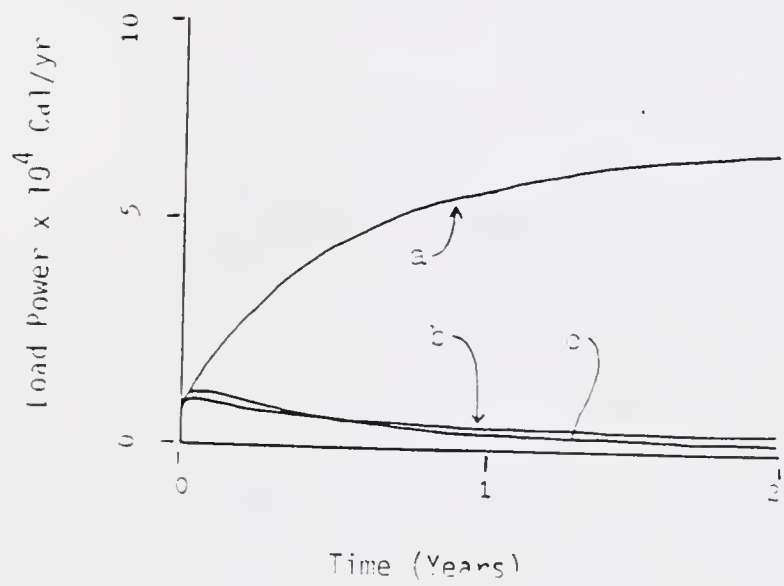
Essentially, the principle of maximum power, describes a system structure that gets the most power for available energy input while at the same time utilizing that input power most efficiently. Efficient power transfer, therefore, becomes an important characteristic for stable system behavior. Were systems to reward selfish producers or consumers the system would be relegating itself to receiving less energy from components lower on the food chain (than would be expected by the Principle of Maximum Power), and as a consequence would support a more limited food chain.

One way for a system to maximize its power input while insuring stability over a wide range of inputs is to develop producers and consumers that create or occupy specific spaces or niches. A system

Figure 24: Plot of power transfer for the energy-selective producer. Power transfer to the load (the rest of the system) via pathway F3 reaches a maximum when the internal rhythm of the producer equals the external oscillation of the source.



(a)



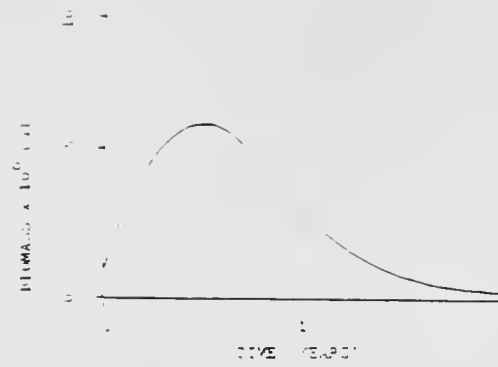
(b)

structure composed of units that provide the most power transfer to the next unit in the food chain, with the most efficient use of power, not only generates more diversity but also provides for the maximum number of units with the most efficient use of input energy. Simply stated, the best way to maximize system power is to provide a means of selecting the greatest number of most efficient biological units. Diversity, created by components that are energy-selective, produces both stability and maximum power transfer. A second inspection of the plots in Figures 24a and 24b indicates that energy input and power transfer to the next component within the system (via pathway F3) are most efficiently accomplished when the rhythm of the source energy is the same as the producer's fundamental or free-running rhythm.

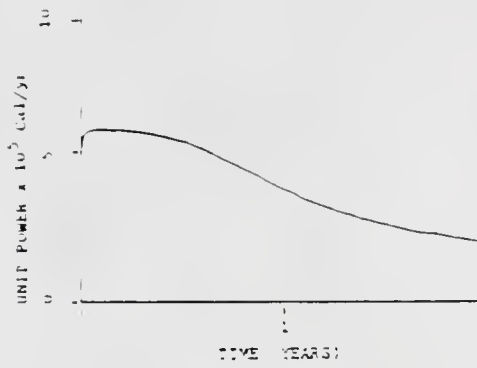
Figure 25a through 25c shows the biomass and power levels for an energy-selective producer with an internal period much larger than the rhythmic period of the available source energy (Figure 25d). While the outcome of this plot indicates death for the producer the initial peak in biomass level might indicate an early successional producer. The unit exhibits an ability to attract energy rapidly but for only a relatively short period of time. The result of such behavior favors the early development of the unit but provides the unit with a short existence, therefore a large amount of biomass is generated early in system's development. A behavioral pattern that allows units to generate large quantities of biomass quickly but provides only a short existence could provide the system with a means of readying an inadequate environment for future more complex biological activity.

Figure 25: Plot of biomass, unit power, and power transfer vs. time for an energy-selective producer with an intrinsic rhythm much larger than the available energy oscillation. Producing units which exhibit this type of behavior (the rapid generation of biomass with no longevity) are often called early successional forms.

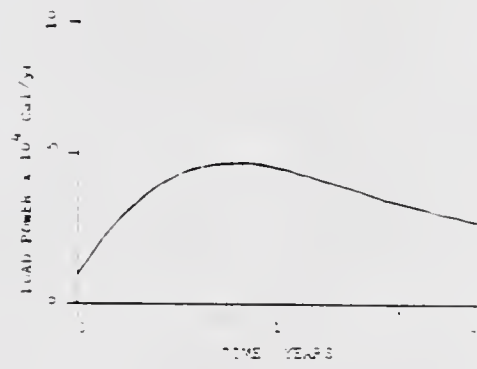
(a)



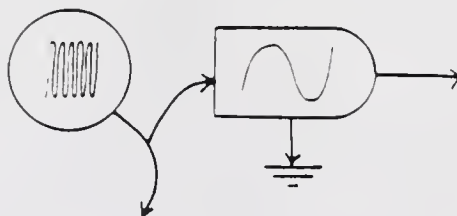
(b)



(c)



(d)



Competition Between Energy Selective Units

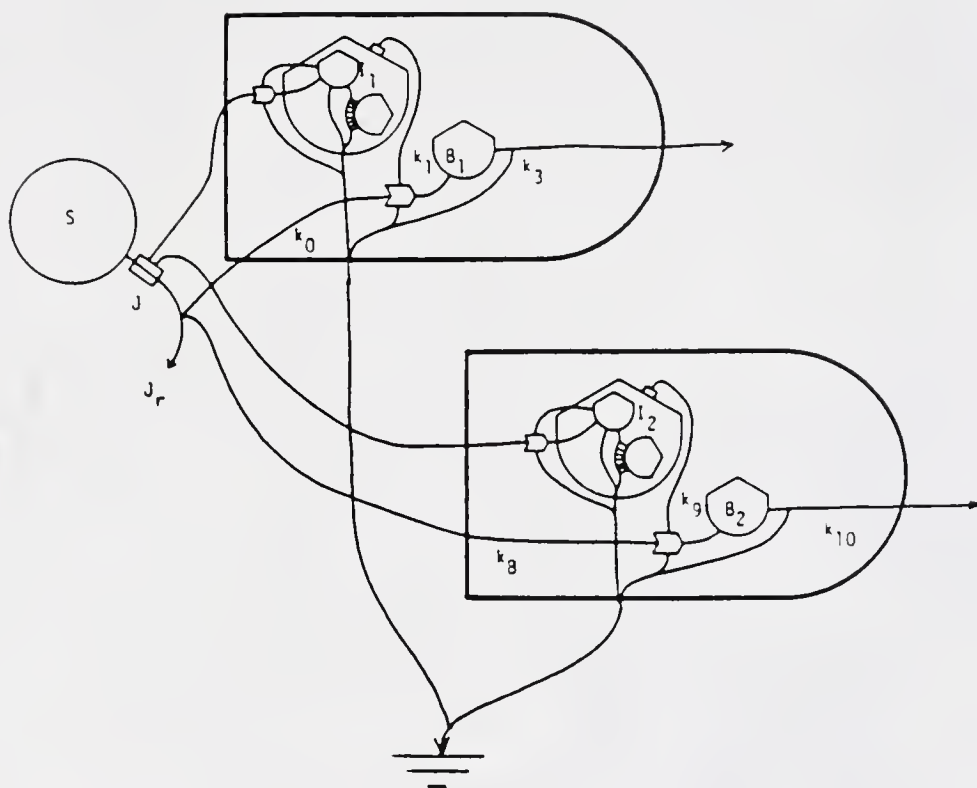
Within this section are the figures, plots, and tables indicating the effects of energy-selective competition on a variety of hypothetical biological units. The intent is to present a theory for competition based upon the energy-selective behavior exhibited by one or all of the competing units. The following nine simulations present various combinations of energy-selective producers in competition with each other for limited resource.

Figure 26 is an energy diagram depicting competition between two energy-selective producers. Table 4 presents the storage initial conditions, a descriptive comment, pathway coefficients, and equations for the model. This diagram is used for the majority of the nine simulations, and is only repeated within the simulation sections where the model is modified for that particular simulation. Each simulation represents a change in either the energy selectivity of one or both of the competing units or a change in the source supply rhythmic pattern. Each unit employs an autocatalytic internal oscillator that governs the unit's behavior. The inertial oscillators sense the environment and produce an internal activity which defines the units' energy acceptance niche.

The following description of the model is general and each simulation incorporates some new combination for competition between the energy-selective units within the model. However, the description provides a general understanding of the model's design.

Producer #1 (the producer with the shortest free-running internal period) a specialist in comparison to unit #2. However, the two producers are identical in all respects except for coefficients k_7 and

Figure 26: Energy-selective competition. The model has two energy-selective units in competition with one another. The models is employed to simulate a series of competitive situations. In all situations the model shows the producer with the shortest period for its internal rhythm in the upper left corner. Thus the specialists is in the upper left corner and the generalist is in the lower right corner.



$$J_r = J / (1 + k_0 I_1 + k_8 I_2)$$

$$dB_1/dt = k_0 I_1 J_r - k_3 B_1$$

$$dB_2/dt = k_8 I_2 J_r - k_{10} B_2$$

Table 4: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Model for Energy Selective Competition

Component/Storage/Flow	Value	Name or Description	Equation
Biomass ₁	1.0E+6	Cal Biomass for producer #1	$k_1^*l_1^*dr-k_3^*B_1$
Biomass ₂	1.0E+6	Cal Biomass for producer #2	$K_9^*l_2^*dr-k_{10}^*B_2$
P ₁	1.0E+5	Cal Potential energy clock #1	$Pin_1^{**2}/(2^{**c})$
P ₂	1.0E+5	Cal Potential energy clock #2	$Pin_2^{**2}/(2^{**c})$
K ₁	0.0	Cal Kinetic energy clock #1	$(t_1/2)^{**2}/(116^{**2})$
K ₂	0.0	Cal Kinetic energy clock #2	$(t_2/2)^{**2}/(116^{**2})$
I ₀	3.7E+5	Cal/d Solar energy producer #1	$k_0^*l_1^*dr$
I ₁	3.0E+4	Cal/d Biomass production #1	$k_1^*l_1^*dr$
I ₂	3.7E+5	Cal/d Solar energy sensor	$k_2^*p_1^*dr$
I ₃	1.0E+4	Cal/d Biomass export #1	$k_3^*B_1$
I ₄	3.0E+4	Cal/d Input sensor to clock ₁	$k_4^*p_1^*dr$
I ₅	6.0E+4	Cal/d Autocatalytic feedback of potential energy in clock to sensor	$k_5^*p_1^*dr$
I ₆	5.0E+3	Cal/d Depreciation of clock potential	$k_6^*p_1$
I ₇	5.0E+3	Cal/d Depreciation of clock potential with inertial backforce	$k_7^*p_1$

Note: Table for Figure 26.

Table 4. (cont.)

Component/Storage/Flow	Value	Name or Description	Equation
f_8	3.71×5	Cal/d Solar energy sensor	$k_8^* f_2^* j_r$
f_9	3.01×4	Cal/d Biomass production #2	$k_9^* f_2^* j_r$
f_{10}	1.01×4	Cal/d Biomass export #2	$k_{10}^* B_2$
f_{12}	3.01×4	Cal/d Input sensor to clock ₂	$k_{12}^* p_2^* j_r$
f_{13}	6.01×4	Cal/d Autocatalytic feedback of potential energy in clock to sensor	$k_{13}^* p_2^* j_r$
f_{14}	3.71×5	Cal/d Solar energy to producer #1	$k_{14}^* p_2^* j_r$
f_{15}	5.01×3	Cal/d Depreciation of clock potential	$k_{15}^* p_2$
f_{16}	5.01×3	Cal/d Depreciation of clock potential with inertial backforce	$k_{16}^* p_2$
b_7	w_1^2	Period setting coefficient producer #1	$2.0^* w_1^* f_{01}$
b_{16}	w_2^2	Period setting coefficient producer #2	$2.0^* w_2^* f_{02}$

k16 which set the free-running internal rhythms for their respective autocatalytic inertial oscillators. The source rhythmic pattern is a composite cycle having a diurnal and annual component to its available energy. Each producer, as a result of its internal behavior, senses the source's rhythmic pattern and selectively regulates the production of unit biomass based upon its acceptance or rejection of available energy. The two producers compete for available energy, however their internal behavioral characteristics determine which producer is more capable of utilizing part or all of the energy.

Power transfer for both units is determined by the amount of energy flow per unit time along four pathways F0, F8, F3, and F10. The energy flow per unit time (power) via pathway F0 is the power required by unit #1. Pathway F8 provides the power demanded by producer #2. The summation of energy within pathways F3 and F10 determines the amount of power transfers from each unit to its respective load, i.e. the remainder of the system. The diagram shows pathways F3 and F10 as open ended and indicates that these pathways transfer energy and power to other components or to a more complex system. The producer that acquires the most input power, utilizes that power most efficiently, and transfers the greatest amount of power to its load (the rest of the system) survives in competition, and successfully fills a niche within the system.

Simulation 1: Competitive Exclusion of a Simple Generalist by a Specialist

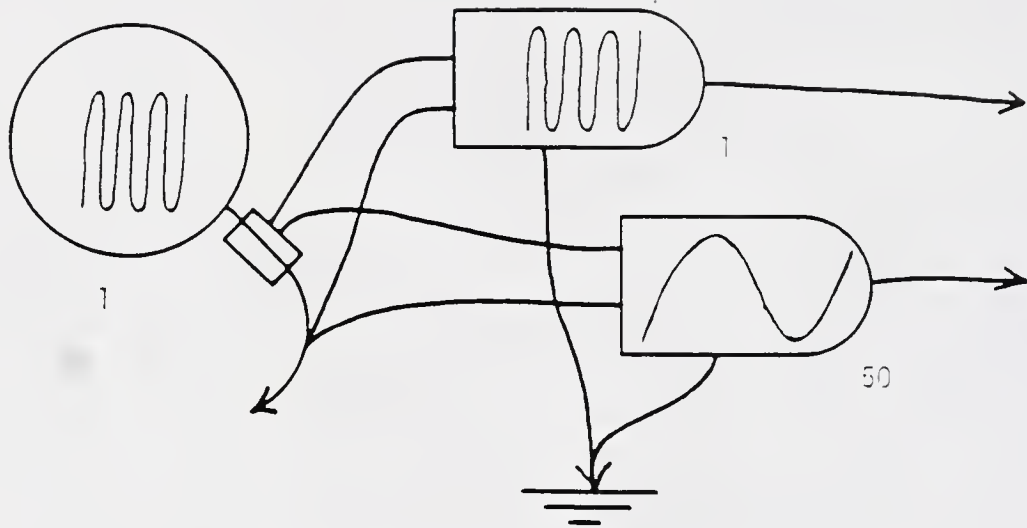
This simulation shows the effects of energy-selective competition for input rhythmic energy between a specialist (the short rhythmed producer) and a generalist (the long rhythmed producer). The model in

Figure 27a shows the relative period relationships between the source and the competing producers. The niche plots in Figure 27b indicates the relative (for visual aid only) or graphical range of the competitors' energy-acceptance niches. The source energy is available only at the intrinsic rhythm of the specialist producer and provides that unit with a competitive advantage.

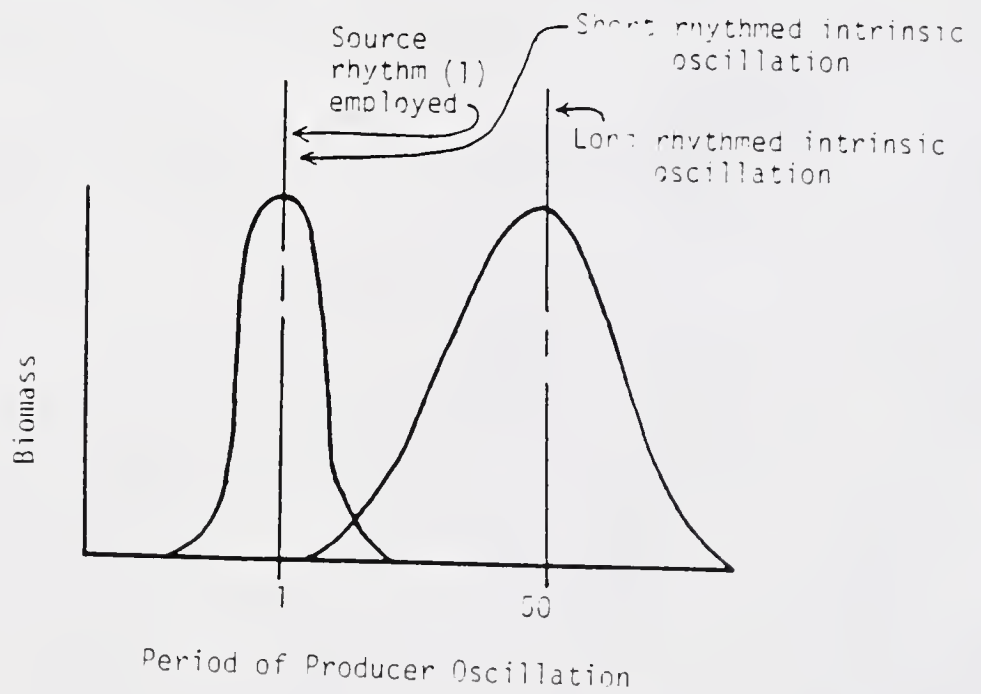
Figure 28 shows the simulation plots for competition between two energy-selective producers. Producer #1, the specialist, employs an intrinsic free-running rhythm period of 1 day. The generalist, unit #2, utilizes an intrinsic rhythm with a period of 50 days. The specialist clearly outcompetes the generalist reaching a maximum biomass level of 8.0×10^6 Cal.

The competition between these two producers results in the competitive exclusion of the generalist by the specialist. The initial success of the generalist is attributable to the longer period of its internal free-running behavior. Units with longer internal free-running rhythms initially begin to store a greater amount of energy, thereby, producing an initial rapid increase in their biomass. However, the consequence of this behavior over a long period of time results in the exclusion of unit with the longer internal period because the production of biomass is not supported by the interaction of source energy with internal behavior. The two rhythmic energies which combine to generate biomass for the long period producer (its autocatalytic inertial oscillator and the source) counteract each other more often than they complement one another, leading to the exclusion of this producer.

Figure 27: Simulation 1 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The diagram shows only the relative system periods and niches not the actual periods and energy-acceptance niche curves. The diagram is presented to aid in understanding the intrinsic rhythms of the competing producers. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 50 days. The source energy is cyclic at a period equal to that of the short period producer and as a result the short period producer links well with the source.



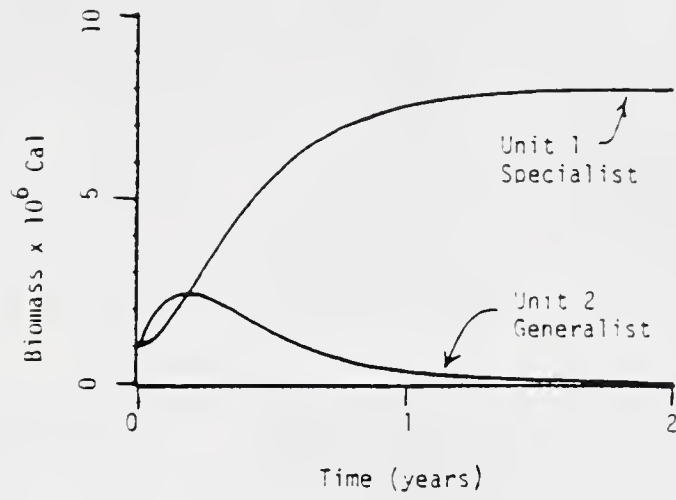
(a)



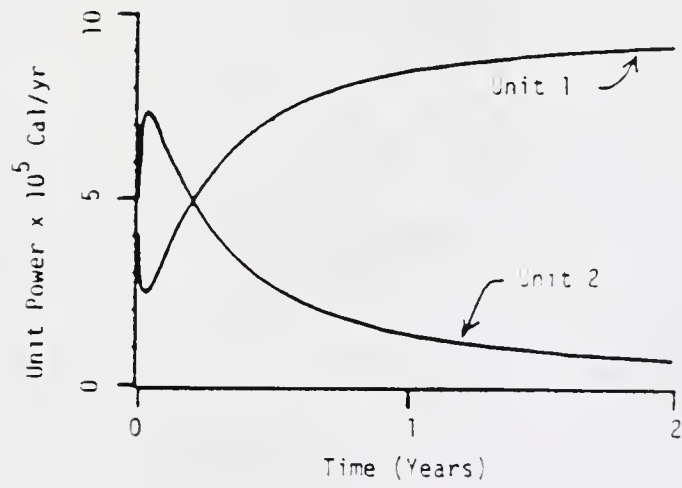
(b)

Figure 28: Plots for competition between a specialist and a simple generalist. Plot (a) the amount of biomass is greater for unit #1 because it specializes in the frequency of the energy source, (b) the power of unit #1 is greater than that of unit #2 because unit #2's rhythmic behavior produces activity too far removed from that of the source, (c) power transfer for unit #1 is clearly greater than that of unit #2 and therefore unit #1 is of more importance to the next larger system.

(a)



(b)



(c)

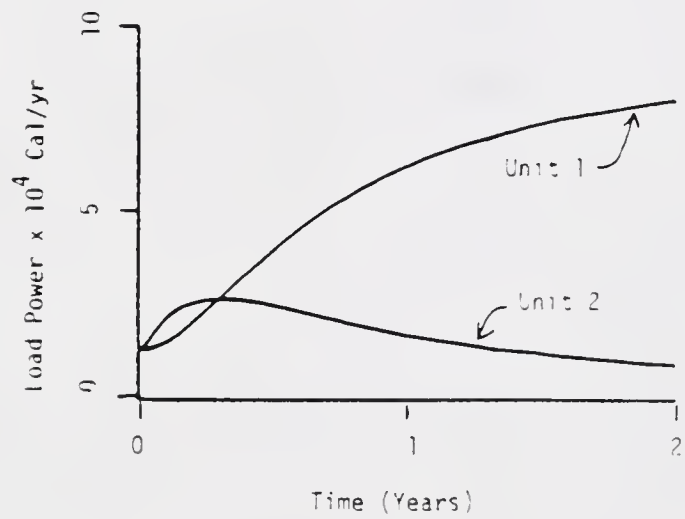


Figure 28b and 28c indicate the effects of competition on the power demand and transfer for both units. The specialist receives more power from the source and as a result transfers more power to the system via pathway F3. Figure 28b indicates that power demand for specialist unit #1 reaches a maximum at 9.8×10^5 Cal/year, while the level for the generalist decreases to 1.0×10^5 Cal/year. The power demand by the specialist levels and thereafter remains relatively constant at its maximum rate of consumption. Figure 28c shows that the power transfer by unit #1 far exceeds that transferred by unit #2 and reaches a maximum of 7.0×10^4 Cal/year, or approximately 7.0% of the power utilized by the unit. The power transfer for the generalist reaches a maximum of 2.5×10^4 Cal/year within the first months of the simulation and thereafter decreases to a minimum level of 1.0×10^4 Cal/year.

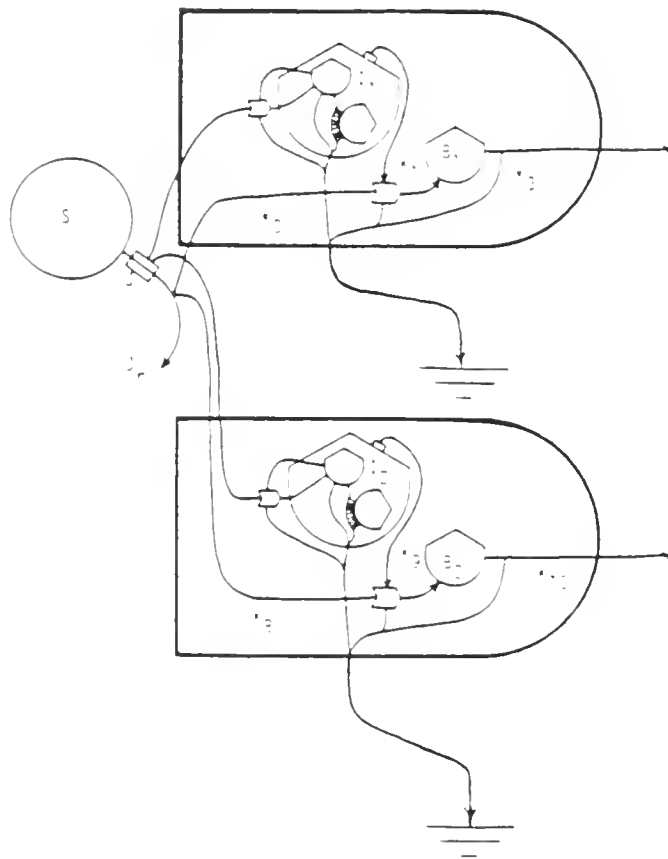
If the specialist producer were a member of a more complex system its greater power transfer would make it more useful to the next level within the system, however for this particular mini-model the remainder of the system is not modelled. The effects of power transfer within web systems are presented later, for the moment, it is more beneficial for the system as a whole if units lower on the food chain transfer more energy/power to the next level in the food chain.

Simulation 2: Competition Between Identical Producers

This simulation was generated to analyze the effects of energy-selective competition between two identical energy-selective producers. The two competitors compete for a source of energy that has a rhythmic pattern that is identical to the internal rhythms of both the producers.

Figure's 29 and 31 show the model and simulation plots for energy selective competition between producers which are alike. The producers

Figure 29: Energy diagram of competition between identical producers. The diagram shows the model for competition between like producers. The two producers are shown side-by-side because they are the same.



$$J_r = J / (1 + k_0 I_1 + k_8 I_2)$$

$$dB_1/dt = k_0 I_1 J_r - k_3 B_1$$

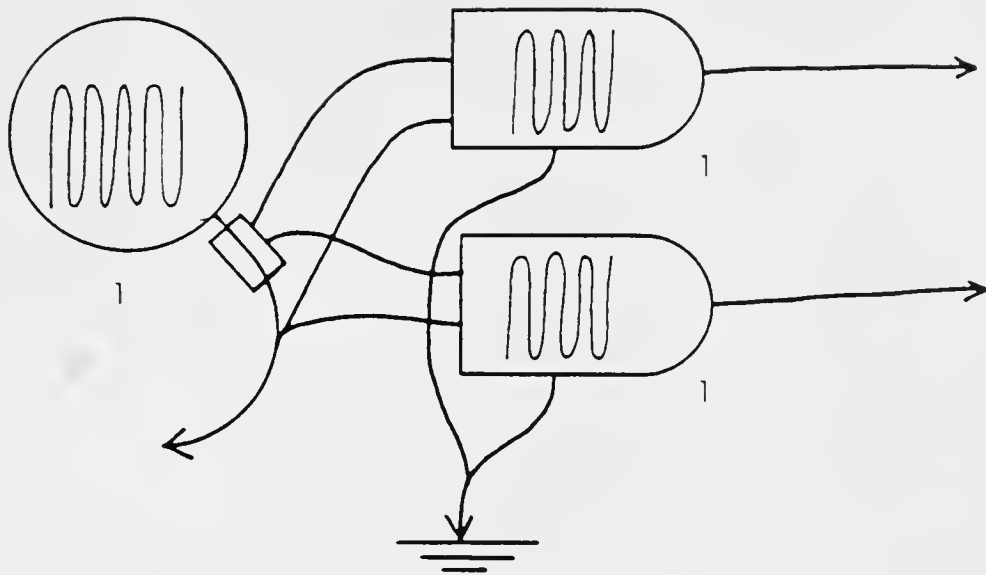
$$dB_2/dt = k_9 I_2 J_r - k_{10} B_2$$

are arranged directly beside one another to indicate their identical behavior. Both producers employ the same free-running internal period for their autocatalytic inertial oscillation, and the pathway coefficients for all pathways and inertial oscillators are identical for both producers. The relative period relationships (Figure 30a) are shown for the source and both competitors and clearly indicates the equality between the competing units. Figure 30b indicates that the producers' energy-acceptance niches are identical.

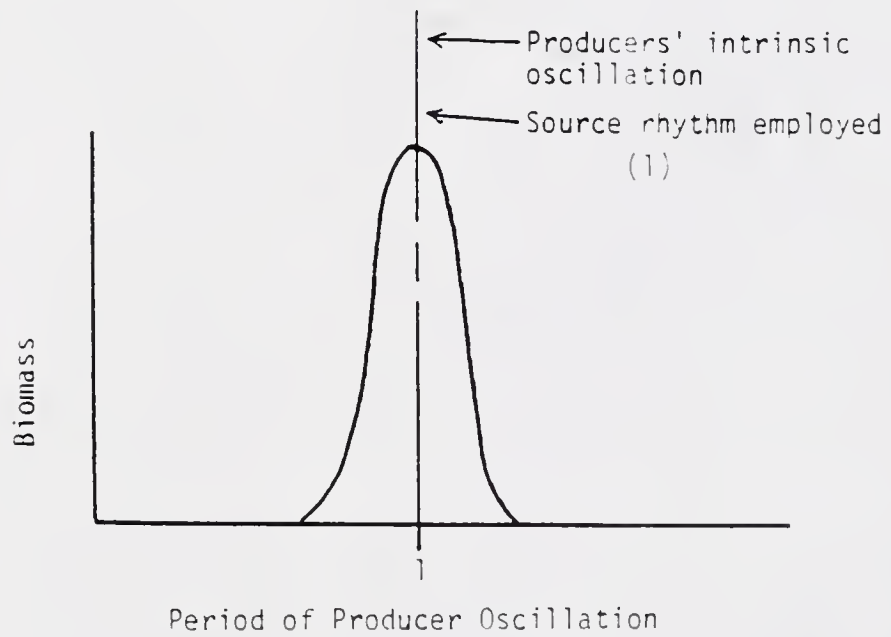
Clearly, the competition is harmful to both units, and the biomass of both units is greatly reduced by the competition. Biomass levels for both units reach a maximum of 4.0×10^6 Cal. These levels represent a decrease of approximately 50% from levels obtainable by each individual producer without the presence of competition. However, both units survive and coexist within an identical niche. It should be noted that the units are exactly identical in all respects. Were the flow coefficients for the various pathways within the producers to differ, while their autocatalytic inertial oscillators remained identical, one or the other would benefit more from the competition. The ultimate effect of the competition would then depend on the competitive advantage provide by other aspects of the unit's internal composition.

Figures 31b and 31c show the power required by the individual units and the power transferred through these units to the system. Power demand by both units reaches a maximum of 5.0×10^5 Cal/year. Both units transfer 4.1×10^4 Cal /year via pathways F3 and F10. Power transfer to the system remains high or unaffected because both units transfer an identical amount of power to the remainder of the system.

Figure 30: Simulation 2 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The producers have a rhythm of 1 day as does the source energy. Both producers link well with the source and compete equally well for the available energy.



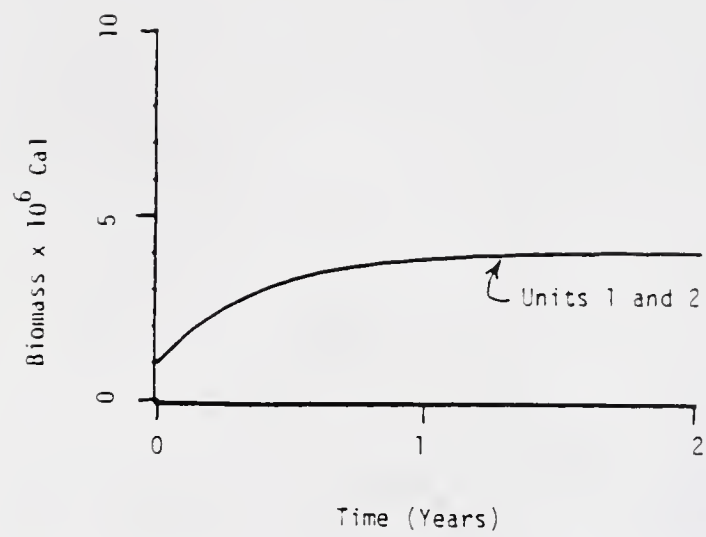
(a)



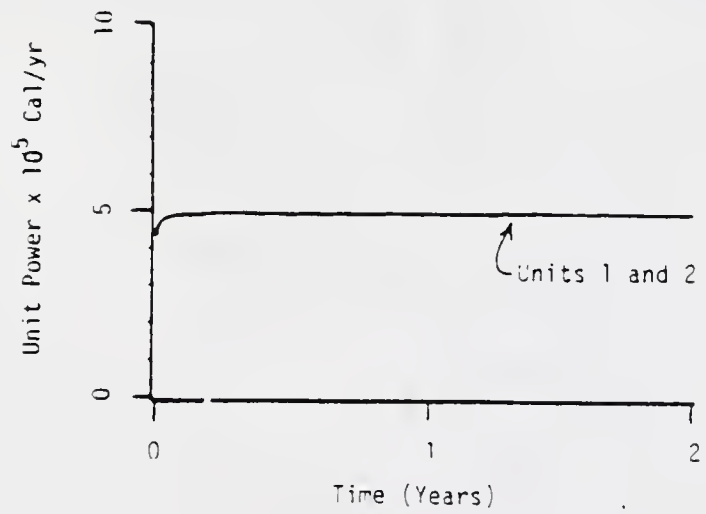
(b)

Figure 31: Plots for competition between identical energy-selective producers. Plot (a) biomass. Plot (b) unit power. Plot (c) power transfer. The producers act identically and therefore one can not outcompete the other. The overall power transfer to the system remains high because each unit transfers $1/2$ the power transfer of an individual unit.

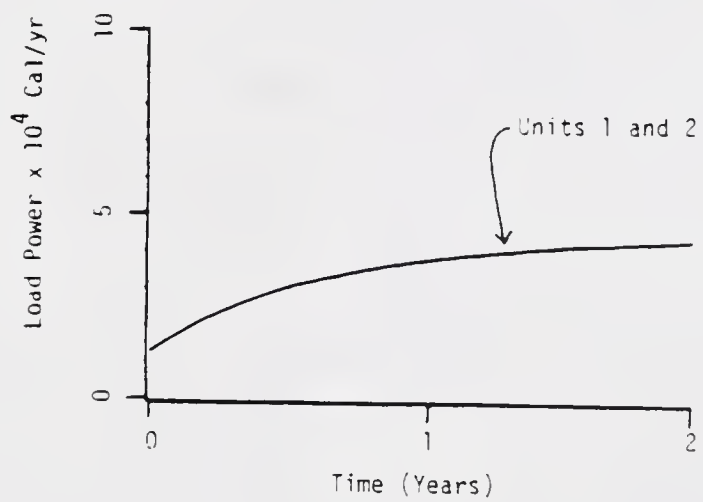
(a)



(b)



(c)



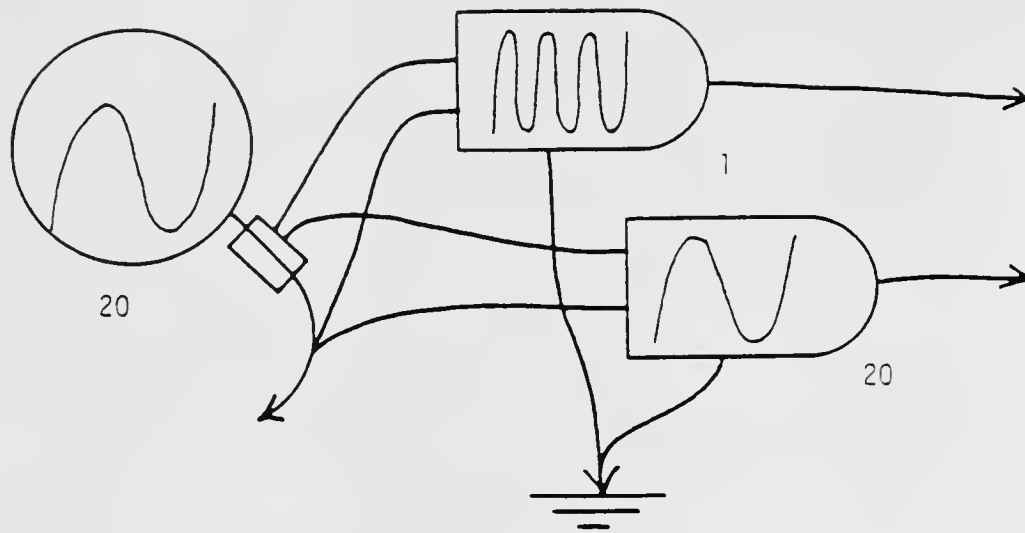
The producers exhibit identical biomass production and power transfer because their intrinsic behavior is identical. Although no two producers are identical in every respect the model and simulation serve to show the effects of intraspecific competition in its purest form.

Simulation 3: Competitive Exclusion of a Specialist by a Simple Generalist

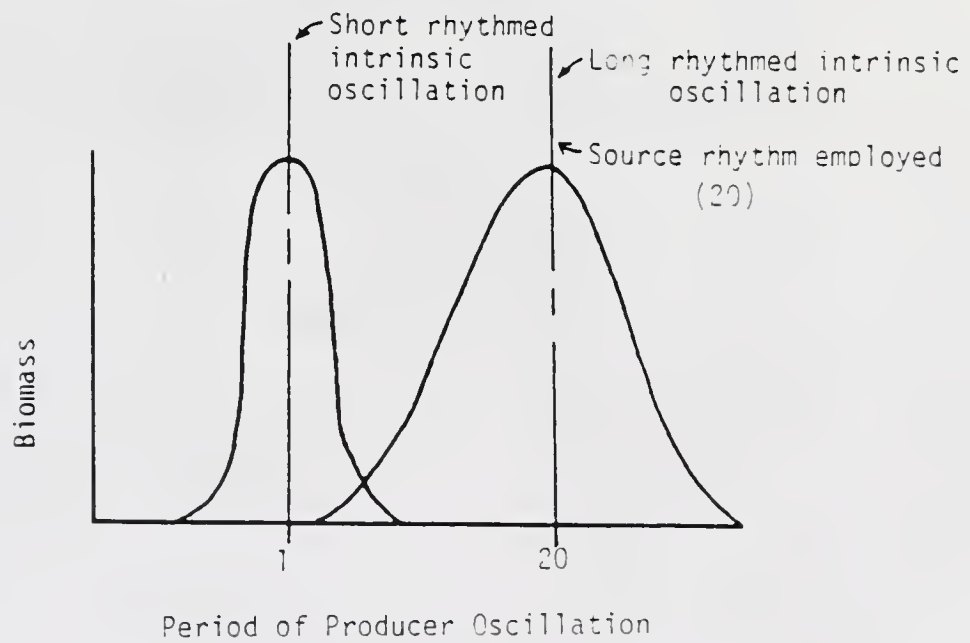
This simulation was generated to analyze the effects of energy-selective competition between two energy-selective producers. The model was employed to investigate the competitiveness of a generalist that is in tune with its environment. Unlike the previous simulation the specialist does not link well with the environment but the generalist does link effectively to the environment. The producers have energy-acceptance niches generated by their internal rhythmic behavior. The source rhythm oscillates at the same frequency as the long rhythm of the producer or generalist and the relative period relationships between the source and the two producers are shown in Figure 32a. Relative period diagrams are used here to indicate that there is a marked difference between the periods of the system components--the diagrams do not show the actual relationship between the rhythm periods because the difference is often in orders of magnitude and could not be plotted in a reasonable manner for presentation. A graphical representation of the relative energy-acceptance niches (also distorted and intended for visual aid only) for the two competing producers is shown in Figure 32b. The diagram indicates that the source input energy is available at the same frequency as the internal rhythm of the generalist producer unit.

Figures 33a through 33c show the effects of energy-selective behavior for two producers. The generalist employs the longest

Figure 32: Simulation 3 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The diagram shows only the relative system periods and niches not the actual periods and energy-acceptance niche curves. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 20 days. The source energy is cyclic at a period equal to that of the long period producer and as a result the long period producer links well with the source.



(a)



(b)

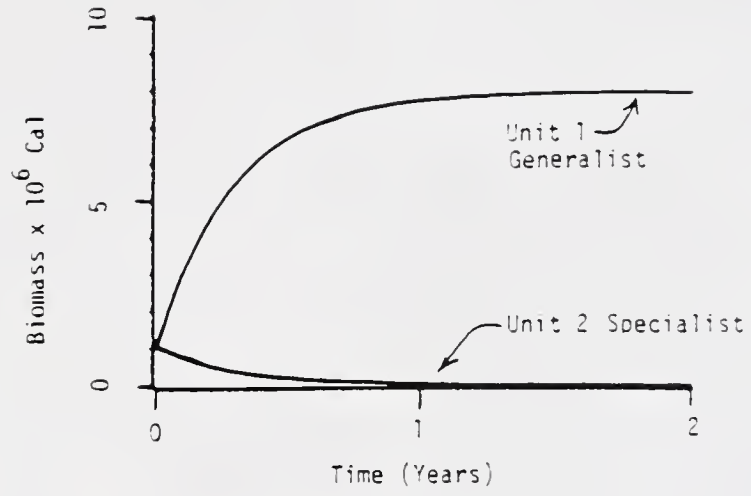
intrinsic rhythm of the two competing producers, and easily outcompetes the specialist because the free-running rhythm of the generalist matches the period of the source. The specialist unit develops such a rapid internal behavior it produces an extremely narrow niche outside of which it rejects available energy. On the other hand, the generalist develops an energy acceptance niche close to that of the available energy and therefore accepts energy from the source. The specialist's behavior results in its exclusion by the generalist. The biomass plots in Figure 33a indicate that the generalist easily outcompetes the specialist, producing a maximum biomass level of 8.0×10^6 Cal/year.

Rejection of energy by the specialist does not imply that the unit willingly accepts its own demise. A unit that does not accept an available energy does so because of physical and/or psychological reasons. Two examples of physical rejection include: seed rejection by birds with inadequate bill size and the lack of photosynthetic production for solar radiation with wavelengths outside of the visible light range. An example of psychological rejection is the abstinence from the ingestion of food at the noon meal when dieting.

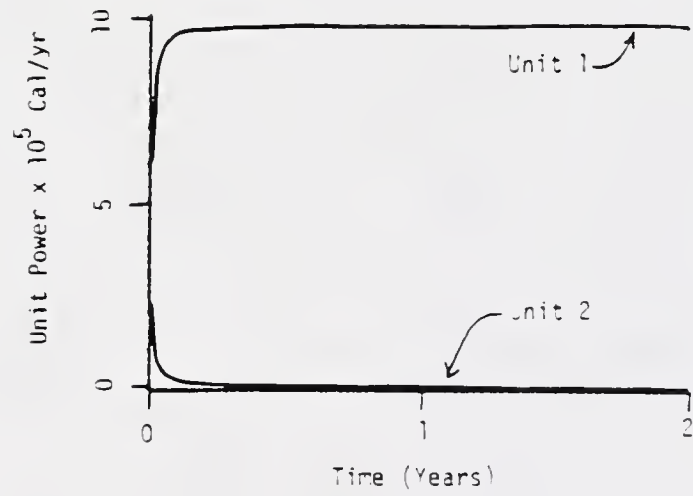
Power requirements and transfer characteristics for the two producers are indicated in Figures 33b and 33c. The generalist producer acquires the most power from the source (9.8×10^5 Cal/year) and transfers more power (7.8×10^4 Cal/year) to the remainder of the system. The plot of unit power (Figure 30b) also indicates that the competition was relatively easy for the generalist. Within a few months it captures a majority of the available energy while at the same time competitively excluding the specialist producer.

Figure 33: Competitive exclusion of a specialist by a simple generalist. Plot (a) biomass levels for the competing units indicates that unit #1 easily outcompetes unit #2, (b) unit power for unit #1 reaches its maximum rapidly because it has a greater competitive edge, (c) power transfer for unit #1 is significantly greater than unit #2 and as a result unit #1 is of greater importance to the next larger system.

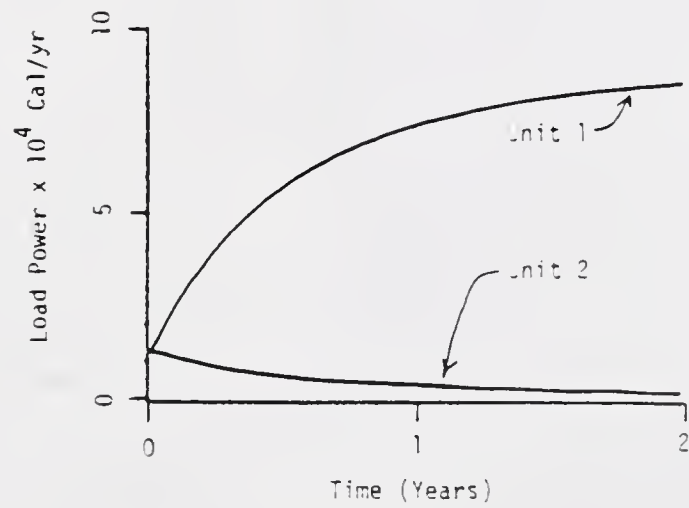
(a)



(b)



(c)



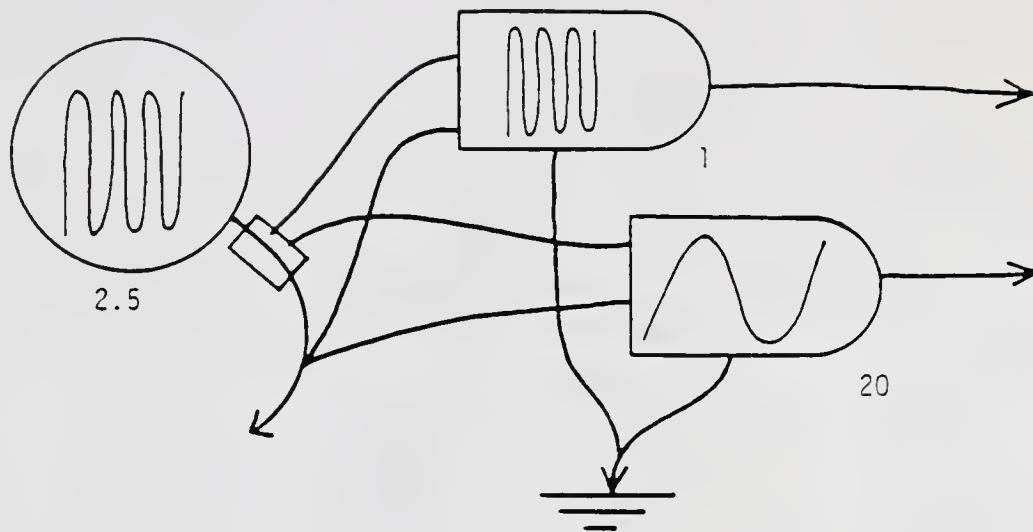
Simulation 4: Competition of two Producers for a Limited Energy Within Their Niche-Acceptance Ranges but not at Either Producers' Free-Running Rhythm

This section describes the results for the computer simulation of energy-selective competition between two competing producers for input energy at a frequency which does not oscillate at either producers intrinsic rhythm. The diagram in Figure 34a shows the relative period relationship for the source and competitors' rhythmic oscillations. The energy-acceptance niches for the two competing producers are shown in Figure 34b, and are graphically represented to depict the specialist-generalist concept for short and long period energy-selective units.

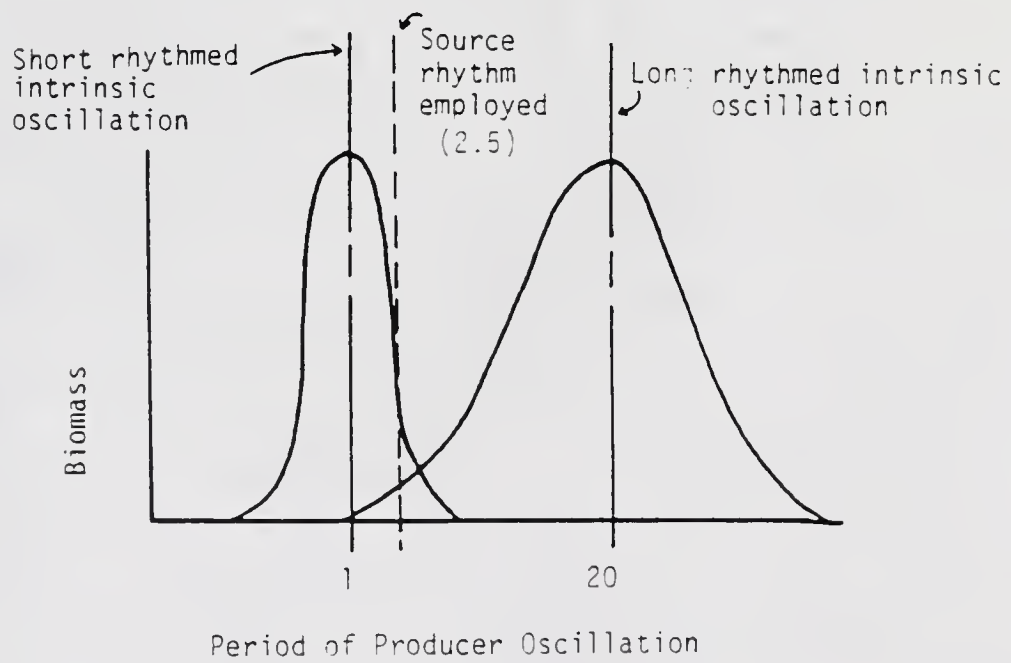
Figures 35a through 35c show the results from the fourth simulation of the competition model shown in Figure 26. The simulation indicates the effects of competition at the extremities of two producers' niches. Producer #1 (the specialist) employs an intrinsic free-running rhythm with a period of 1 day. Producer #2 (the generalist) uses a intrinsic rhythm with a free-running period equal to 20 days, and the source provides a yearly rhythm composed of periods equal to 2.5 days or 52 hours. To simulate the effects of a extended day-night cycle each 2.5 day period generates no source energy supply for 1/2 of the period (1.25 days). The source energy rhythmic period (2.5 day cycle) is therefore closer to the internal rhythm behavior of the specialist.

Figure 35 indicates that the specialist producer outcompetes the generalist, although the competition is intense. The specialist is competing for energy at the edge of its niche width and can not rapidly suppress the generalist unit. Although the generalist uses a longer internal period for behavior and competes well during the early stages of competition it also competes at the limits of its niche. The

Figure 34: Simulation 4 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 20 days. The source energy is cyclic at a period of 2.5 days and is not cyclic at the intrinsic period of either producer. The source period is closer to the rhythm of the specialist producer and as a result the specialist is able to acquire more of the available energy.



(a)

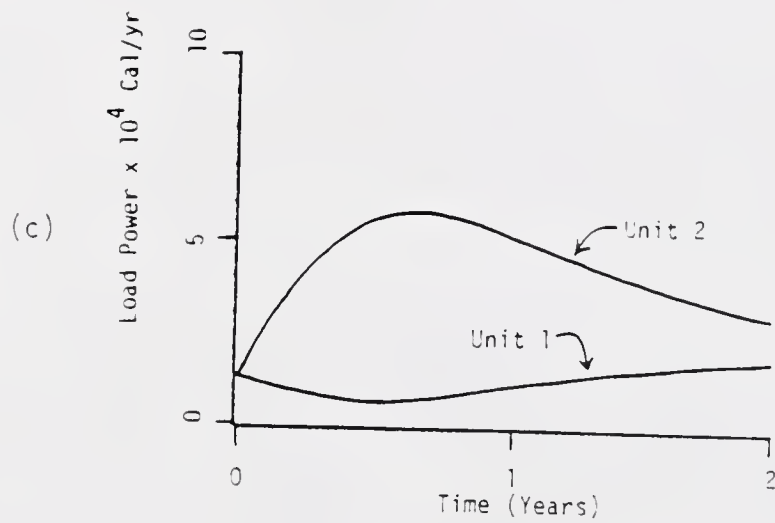
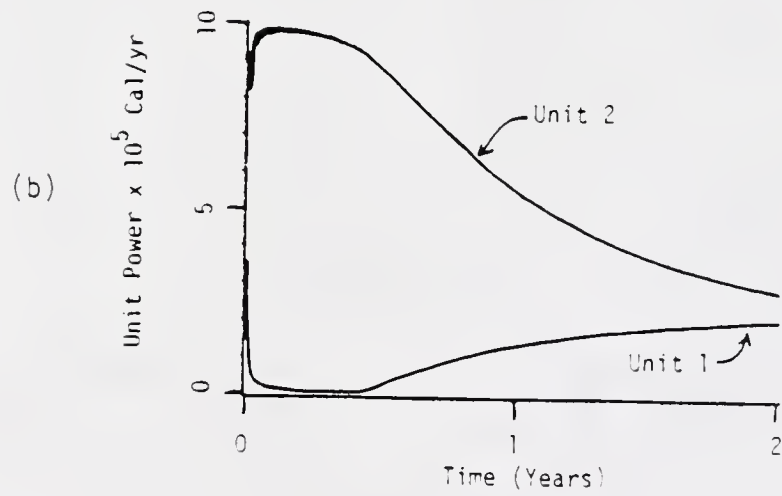
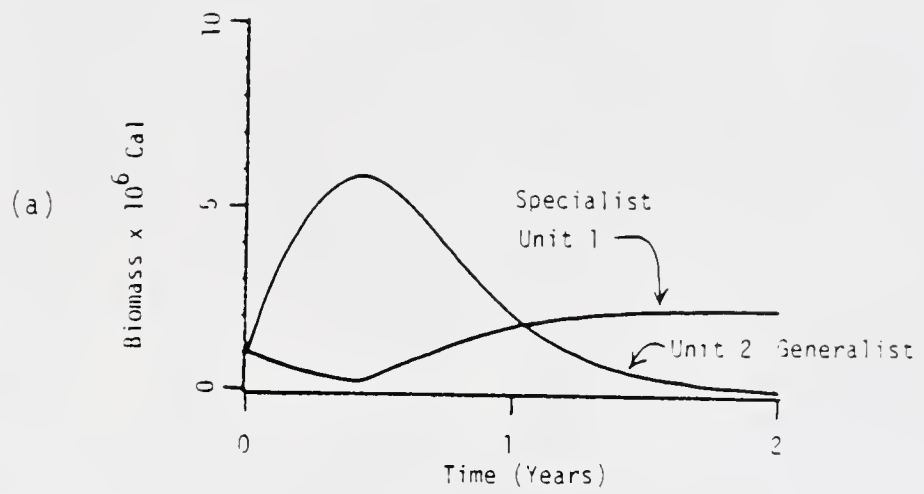


(b)

competitive edge exhibited by the specialist results because the source provides energy within its narrow niche width. The generalist on the other hand, exhibits the same type of early behavior exhibited by the individual producer in Figure 25, i.e. rapid biomass generation as a result of early competitiveness. The behavior of the generalist unit makes it compete well for short periods of time but not in the long term. This type of behavior, rapid early biomass generation and short term competitiveness (perhaps because of energy selectivity), is often described as an early successional stage.

Figure 35b shows the unit power demand for the two producers. During the two year period of simulation the generalist producer exhibits a higher unit power requirement reaching a maximum level at the beginning of the simulation at 9.8×10^5 Cal/year but unit power rapidly reduces as the competition progresses. Early in the simulation the unit power for the generalist exhibits a noise or rapid fluctuation of power input. This fluctuation results from the acceptance of smaller period energies generated by the competitive interaction of the two units and serves as an indication of the ability of energy selective units to utilize energies other than their primary energies within their niche range. The unit power requirements of specialist initially decreases because of the rapid albeit short lived growth in the biomass for the generalist. The behavior of specialist provides the unit with a long term strategy for competitive success, at least for this competitive scenario. The generalist transfers more power to the system during the short term (reaching a maximum of 5.5×10^4 Cal/year, however, the competitive advantage of specialist begins to provide the system with a more stable power transfer for the long term.

Figure 35: Competition at energy niche extremities. Plot (a) biomass levels for the two competitors, the specialist clearly outcompetes the generalist in the long term. Plot (b) unit power the specialist eventually attracts more power from the source. Plot (c) power transfer in which the generalist transfers more power initially, however the specialist transfers more power in the longterm. These plots reflect the fact that the source energy is at a rhythm more closely coupled to the specialist, but not coupled at the specialist's intrinsic rhythm.

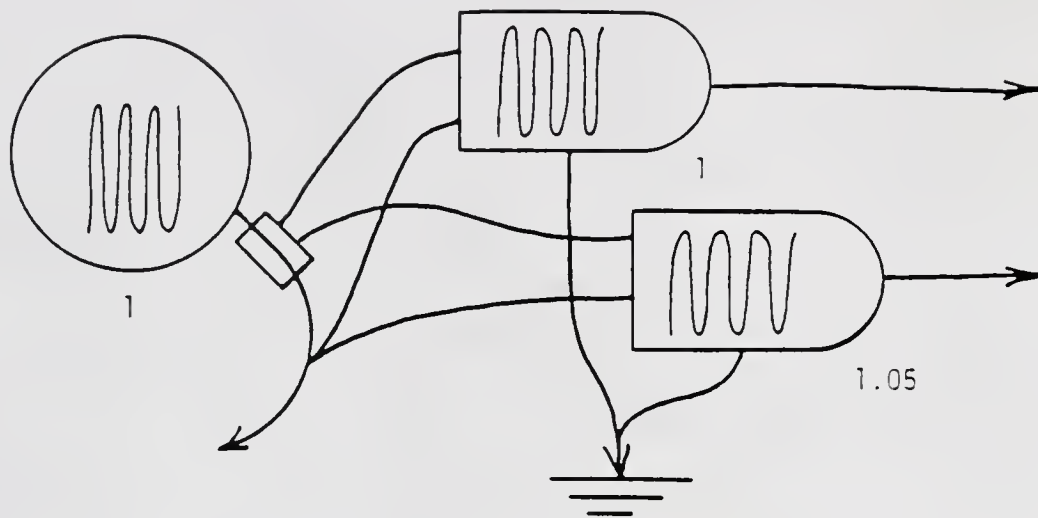


Simulation 5: Competition of Similar Producers With Overlapping Niches

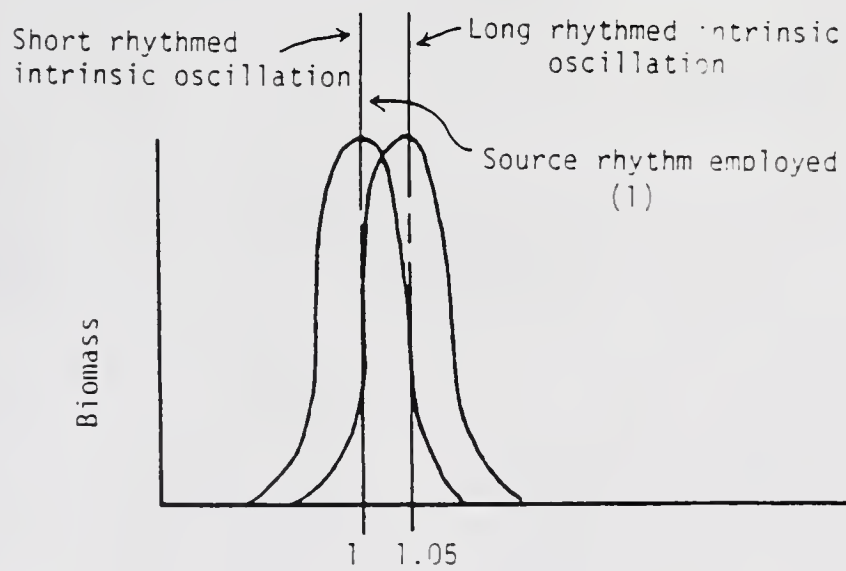
In this section the effects of energy-selective competition between two producers with close intrinsic rhythmic patterns is analyzed. The intent of the simulations was to determine if competitive coexistence might occur as a result of overlapping energy-acceptance niches. The diagram in Figure 36a shows the relative period relationships for the oscillations of the source and the two competitions. Figure 36b shows the relative energy-acceptance niches for the two competitions, and also indicates that the source input energy is at the same frequency as that of the specialist or short rhythmed producer. The diagram indicates that the energy-acceptance niches for the two competitors overlap one another and as a result the competition for input energy is between two producers that have a differential ability to acquire the same energy.

Figures 37a through 37c present the effects of competition between two energy-selective producers with intrinsic behavior patterns that have periods that are only slightly different from one another. The producers could be either specialists or generalists since the concept in this case is a relative term. The free-running period of producer #1 is 1 day and the internal period for producer #2 is 1.05 days. Both units survive the competition producing a competitive coexistence where both units experience decreased biomass production as a result of the competition. Biomass levels reach 6.3×10^6 Cal for unit #1 and 1.9×10^6 Cal for unit #2. Producer #1 acquires the most unit power (7.9×10^5 Cal/year) and transfers more power (7.0×10^4 Cal/year), via pathway F3. Producer #2 obtains or requires less unit power from the source (2.5×10^5 Cal/year) than does unit #1 and also transfers less power (2.1×10^4 Cal/year), via pathway F10.

Figure 36: Simulation 5 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 1.05 days. The source energy is cyclic at a period of 1 day and is cyclic at the intrinsic period of short producer. The source period is also close to the rhythm of the long period producer and as a result the long period producer is able to compete better for a portion of the available energy.

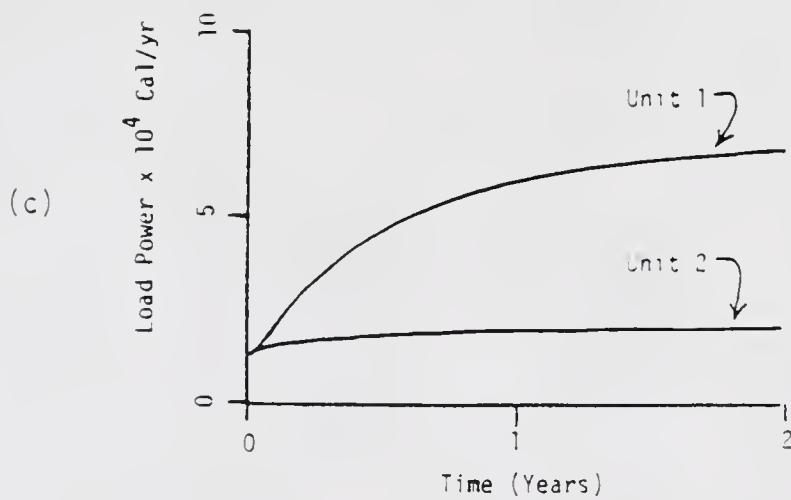
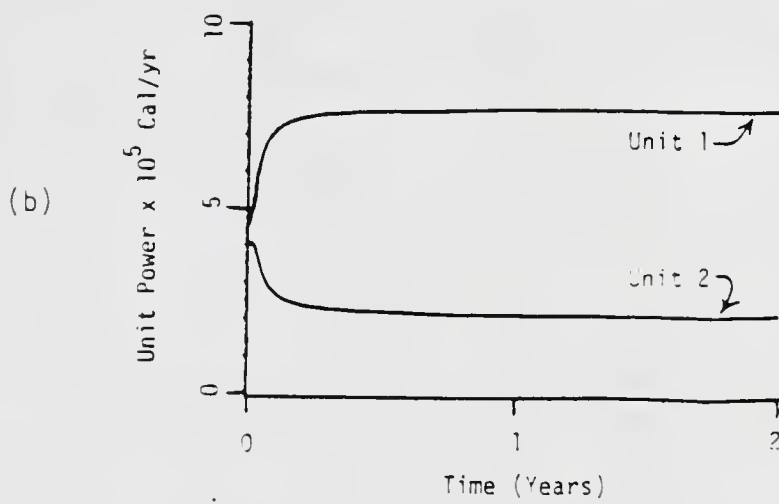
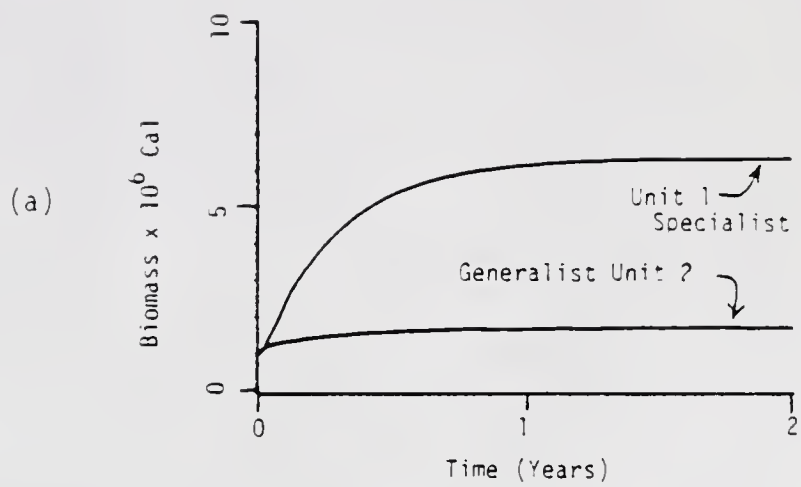


(a)



(b)

Figure 37: Competition of similar producers with overlapping energy niches. Plot (a) biomass. Plot (b) unit power. Plot (c) power transfer. The plots indicate that competitive coexistence occurs when competition is within both competitors' energy acceptance ranges.



Some interesting aspects of this particular simulation include: the quick allocation of input power and the increased diversity of the system. Figure 37 indicates that this type of competition provides both units with a stable relationship, and does so rapidly. Power transfer for both units stabilizes as their biomass levels stabilize. The system receives the same amount of power transfer as it did from the simulations of this model that produced a competitive exclusion of one unit; but the system experiences a higher diversity. Producer #2 experiences a small growth and therefore is considered to be a subordinate species. However, if the intrinsic rhythm of producer #2 is further removed from that of producer #1 and the source, but still within the competitive range of unit #2's niche biomass production would decrease. The resulting competition then places producer #2 to the classification of a rare species.

Simulation 6: Competition for Flow Limited Energy Composed by the Addition of Two Fundamental Cycles About a Supporting Mean Energy Level

The purpose of this simulation was to analyze the effects of competition for energy that is available from the same source but that has frequencies that may be employed by more than one competing unit. The intent of the simulation was to discover if the addition of a second component rhythm to the source might allow the source to support a second energy-selective producer in a competitive environment. Also could the addition of a second rhythm to the source allow for competitive coexistence of producers shown in earlier simulations to competitively exclude when only one source rhythm was available?

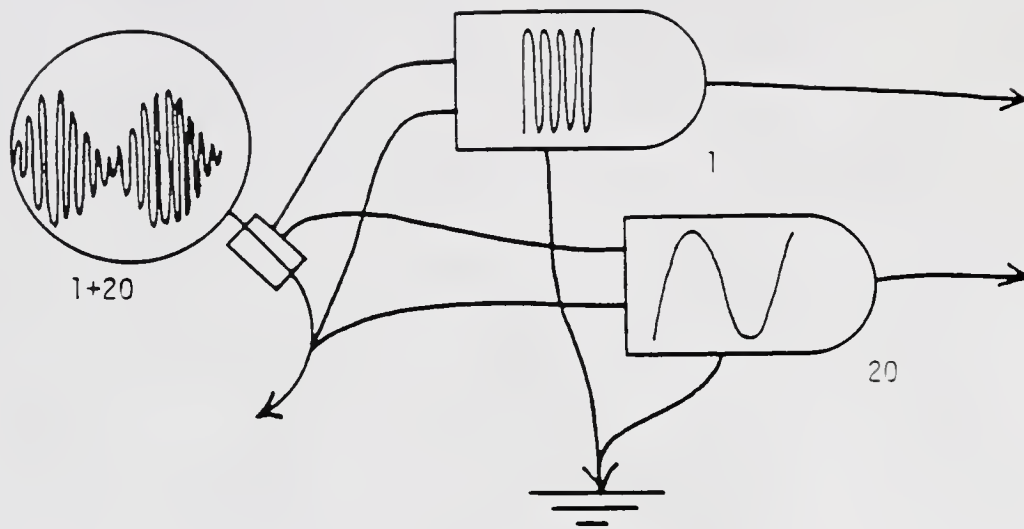
Figure 38a shows the relative period relationships for the source and the two competing producers. The diagram does not show the actual

period relationships and is intended only as an aid to discern the relative differences in frequency for the system oscillations. The energy-acceptance niches for the two competitions are shown in figure 38b. The diagram also indicates that the source rhythm is a combination of the producers' internal rhythms and as a result the competitors each attempt to acquire energy from the same source only at different energy frequencies.

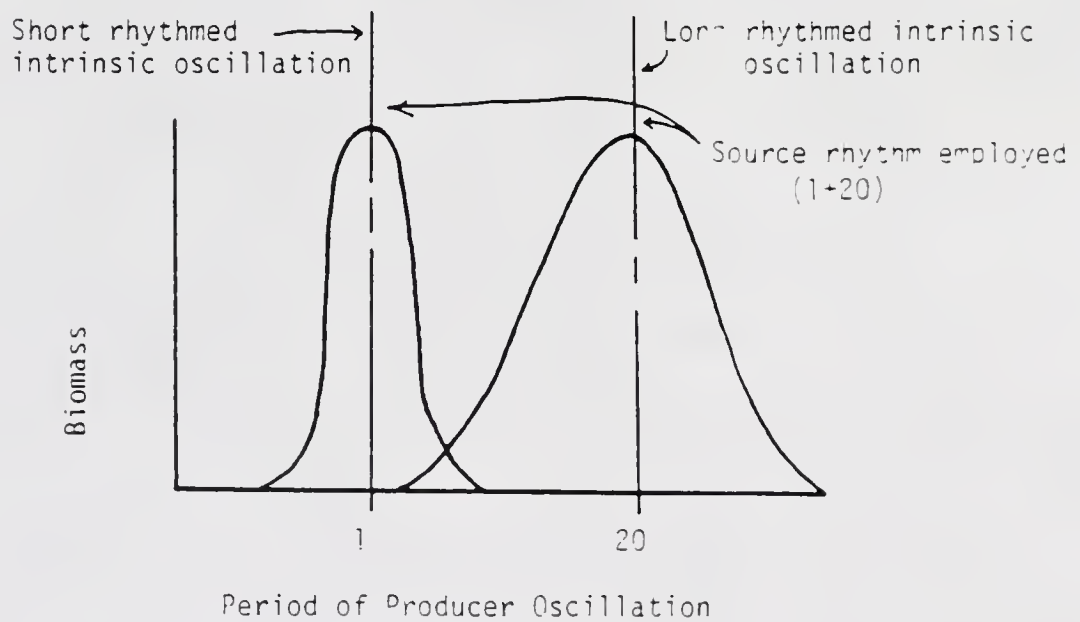
Figures 39a through 39c indicate the effects on biomass, unit power, and power transfer for two competing producers that are in competition for source energy that is flow limited and composed by the addition of two energy cycles. The source energy is composed of two rhythms. The first rhythmic period is equal to 1 day, while the second source period is equal to 20 days. The two competing producers each have only one internal free-running rhythmic period. Producer #1, the specialist, uses an intrinsic rhythmic pattern with a period equal to 1 day. Producer #2, the generalist, uses an intrinsic period equal to 20 days. Consequently, both producers have the ability to link or interact with one of the source's fundamental energy components.

Figure 39 clearly indicates that the specialist successfully outcompetes the generalist--even though the generalist possess the longer internal rhythm. The figure also indicates a fluctuation in the biomass of the specialist at a frequency of 20 days. The fluctuation indicates that the specialist feels the longer period energy, although it may act only to produce the fluctuation. Previous simulation plots indicate that the energy-selective specialist could not accept longer period energy. However, the shorter period intrinsic behavior of the specialist producer provides that unit with a competitive advantage.

Figure 38: Simulation 6 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 20 days. The source energy is cyclic at a periods of both 1 and 20 days and is therefore cyclic at the intrinsic periods of both producers. The short period rhythm supplies more energy to the short period producer than does the long period rhythm for the long period producer. The greater energy input for the short period producer makes it a better competitor.

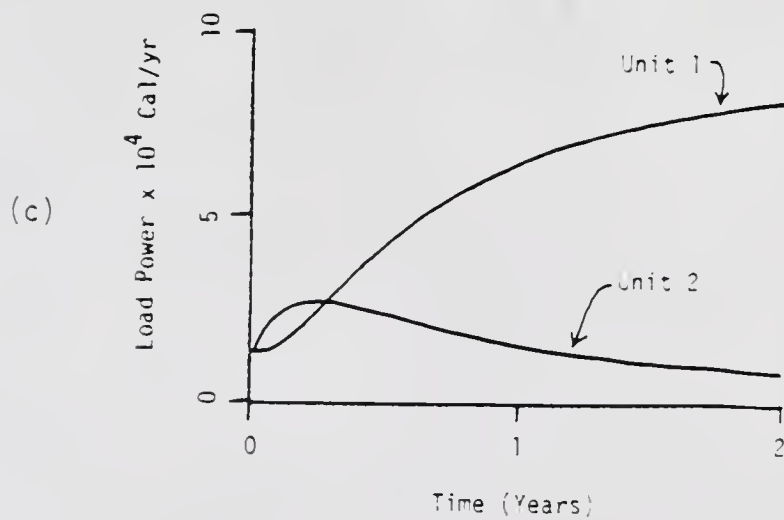
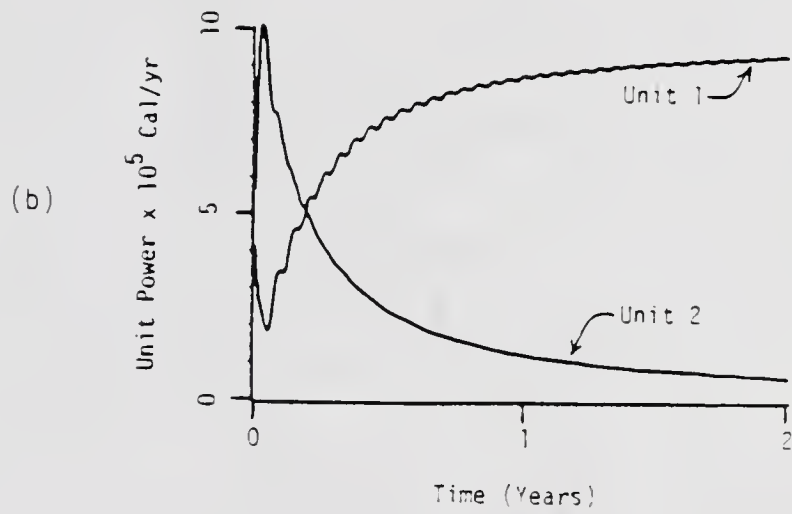
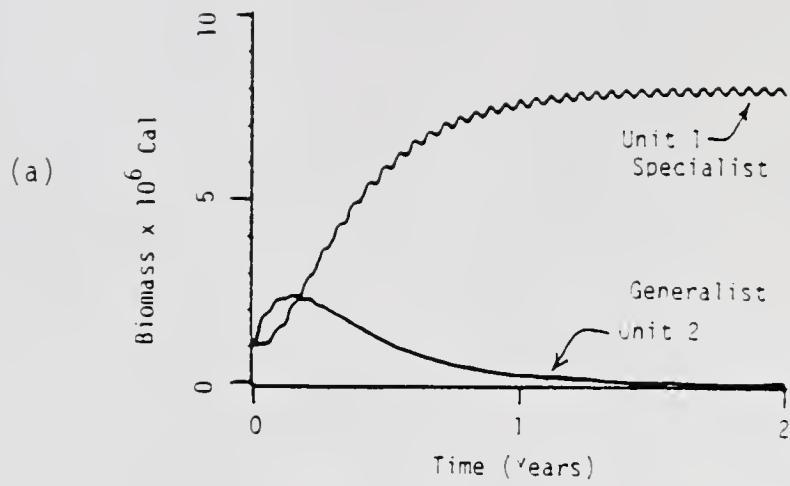


(a)



(b)

Figure 39: Competition for additive energy frequencies by competitors that each match to one of the source frequencies. Plot (a) biomass. Plot (b) unit power. Plot (c) power transfer. The plots indicate that the competitor with the shorter period internal rhythm outcompetes the unit with the longer period internal rhythm. Therefore, when competition occurs for two rhythms from the same energy source (with the same energy quality) the competitor that links to the shorter period energy receives and transfers the most power and survives the competition.



That is not to suggest that a short period source is advantageous, however for the same energy quality, source's with shorter periods provide more power. The short period intrinsic behavior of the specialist unit allows it to draw more energy and power (of the same quality) from the source than does the intrinsic behavior of the generalist. The competition results in the competitive exclusion of the generalist.

Figures 39b and 39c show the unit power requirements and transfer capabilities for the two producers. The specialist clearly obtains more power from the source 8.0×10^5 Cal/year and as a result transfers more power 8.0×10^4 Cal/year to the system. The generalist producer rejects input power in the long term obtaining 1.0×10^5 Cal/year and as a result transfers less power 1.0×10^4 Cal/year to the system. Although the generalist exhibits the early competitiveness shown previously for long period competitors, and suffers the same fate as the its previous counterparts--exclusion by a shorter period, more adapted competitor.

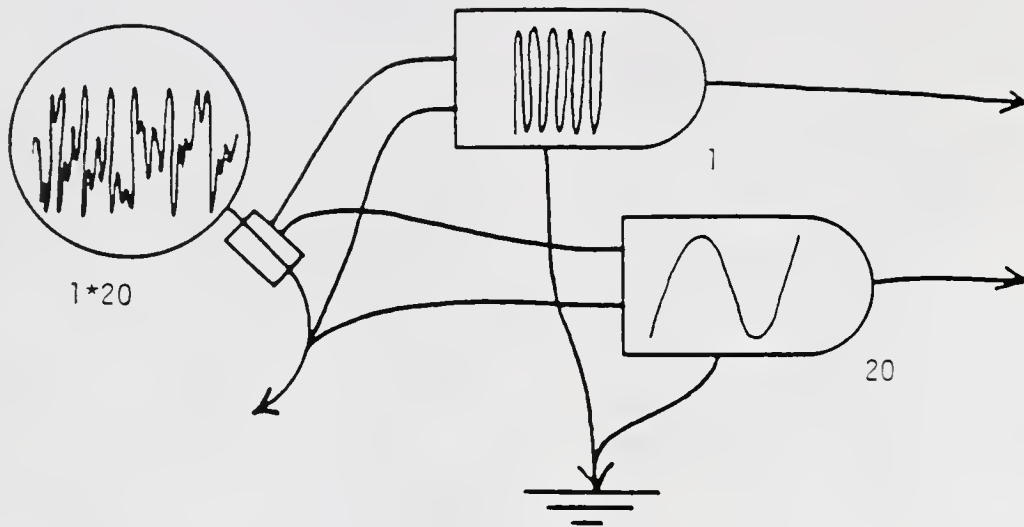
Simulation 7: Competition for a Flow Limited Energy Composed of two Fundamental Cycles by Multiplication About a Mean Energy Level

This section describes the results for competition between two energy-selective producers competing for a dual rhythmmed input energy from the same source. The simulation is much like the previous simulation but the source rhythm construction is different. The difference in the two source rhythms is the reason for this analysis. The intent of this simulation was to discover if the method used by the source to combine the two or more of its rhythms had any effect on the competitive stance of the competing producers.

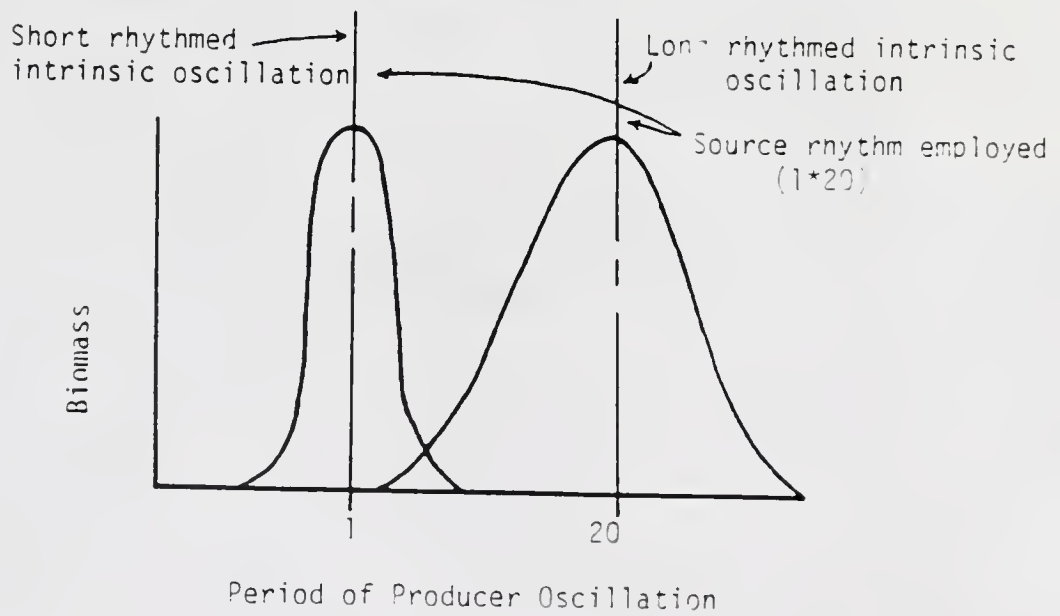
The diagram in Figure 40a shows the relative period relationships for the system, while the niche diagrams in Figure 40b describe the energy-acceptance niches for the competitors. Figures 41a through 41c show the biomass, unit power, and power transfer capability of two competing producers with different fundamental intrinsic rhythmic behaviors. The source energy supply is a combination of two rhythms by multiplication and are supported by or around a constant mean energy level. This simulation is identical to simulation #6 with the exception of the way the two fundamental source rhythms are combined. The first source energy rhythmic period is equal to 1 day with the second rhythm having a period equal to 20 days. The two competing producers are identical to the producers in the previous simulation.

Figure 41 indicates that generation of a source energy supply by multiplication of its two fundamental frequencies increases the competitiveness of the simple generalist. However, the result is the same and the generalist is eventually excluded. The combination of two energy rhythms by multiplication produces more interaction rhythms than does combination by addition and as a result provides the generalist (which uses the longer intrinsic free-running behavior pattern) with a better competitive stance. The more by-product rhythms generated the more possible energy there is available for producers with wider niches. Since the generalist employs the wider of the two niches it obtains more energy than in the previous simulation. The reason the generalist can not outcompete the specialist results from the fact that the specialist obtains more energy from the source's daily rhythm than does the generalist from the combination of the interaction rhythms plus the 20 day fundamental rhythm. The competitiveness of the simple generalist

Figure 40: Simulation 7 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 20 days. The source energy is cyclic at a periods of both 1 times 20 days and is therefore cyclic at the intrinsic periods of both producers. The short period rhythm supplies more energy to the short period producer than does the long period rhythm for the long period producer. The greater energy input for the short period producer makes it a better competitor. However, the side frequencies generated because of the nonlinear multiplication of source fundamental frequencies allows the long period producer to acquire more energy and compete more effectively for energy than in the previous simulation

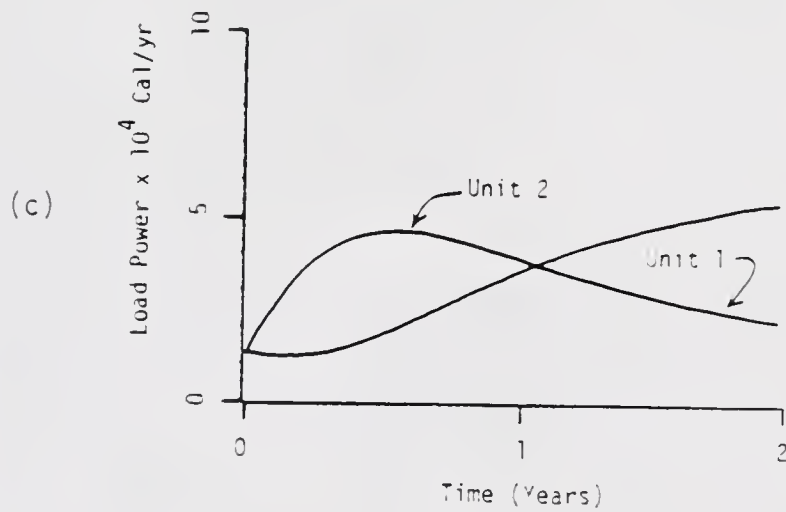
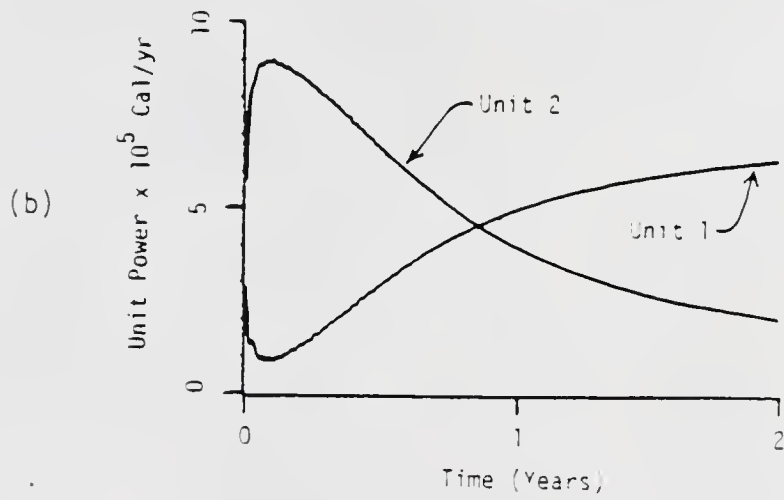
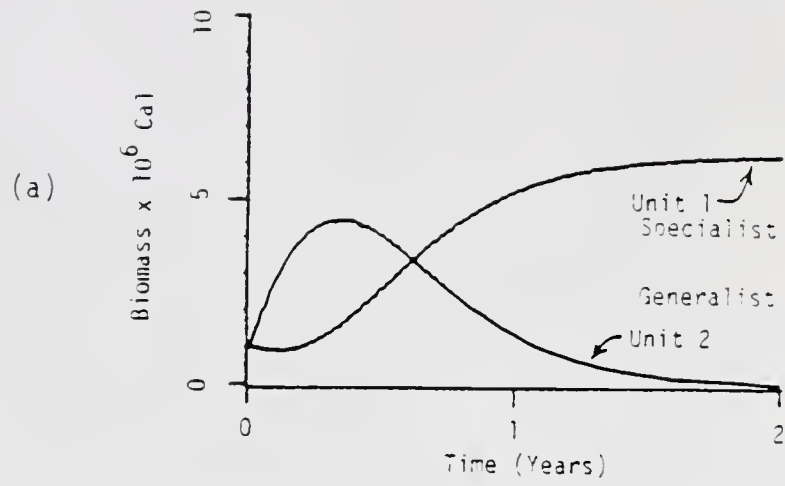


(a)



(b)

Figure 41: Competition for multiplicative energy frequencies by competitors that each match to one of the frequencies of the source. Plot (a) biomass. Plot (b) unit power. Plot (c) power transfer. As with figure 34 the competitor that matches with the shorter period energy from the same quality source survives the competition. However, less power and energy are accepted and transferred when source energy results from the product of frequencies.



does however decrease the steady state biomass and power transfer levels obtained by the specialist unit.

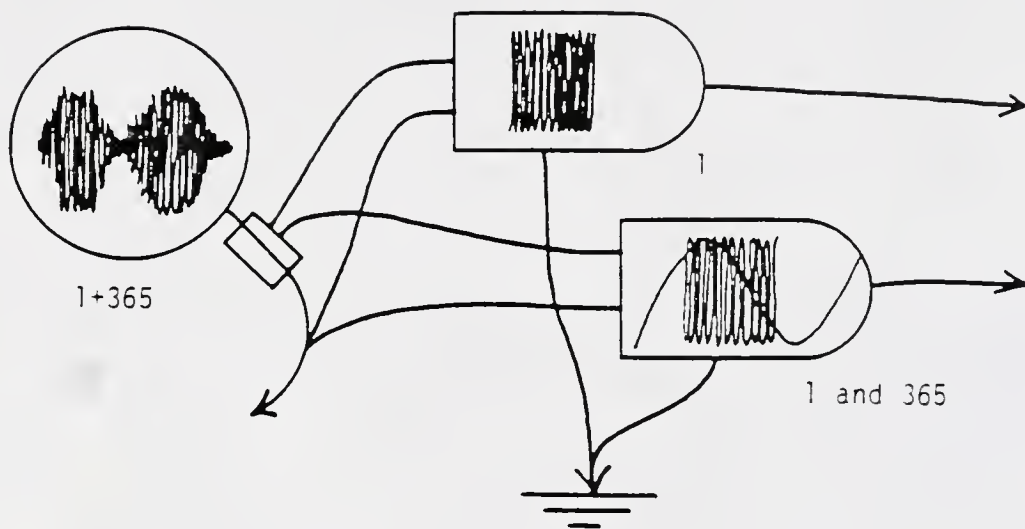
Figures 41b and 41c show the unit and power transfer characteristics for the two competing producers. Initially the generalist accepts the most unit power, however, as the competition progresses the amount of unit power it accepts decreases. The specialist increases its demand for power during the simulation because of its intrinsic behavior. Since the specialist free-running rhythmic pattern matches the daily rhythm of the source's shortest fundamental cycle it eventually obtains more power from the source than does the generalist. Figure 41c indicates that the specialist producer transfers more power than does the simple generalist. The intensity of the competition and the demonstrated ability of the generalist for early competitive success does provide for a considerable power transfer by it during the simulation. Ultimately, the specialist transfers more power to the system and outcompetes the generalist because it possess the ability to accept more energy from the source.

Simulation 8: Competition Between a Two Rhythm Complex Generalist and a Single Rhythm Specialist for a Flow-Limited Source Composed of Two Fundamental Cycles by Addition

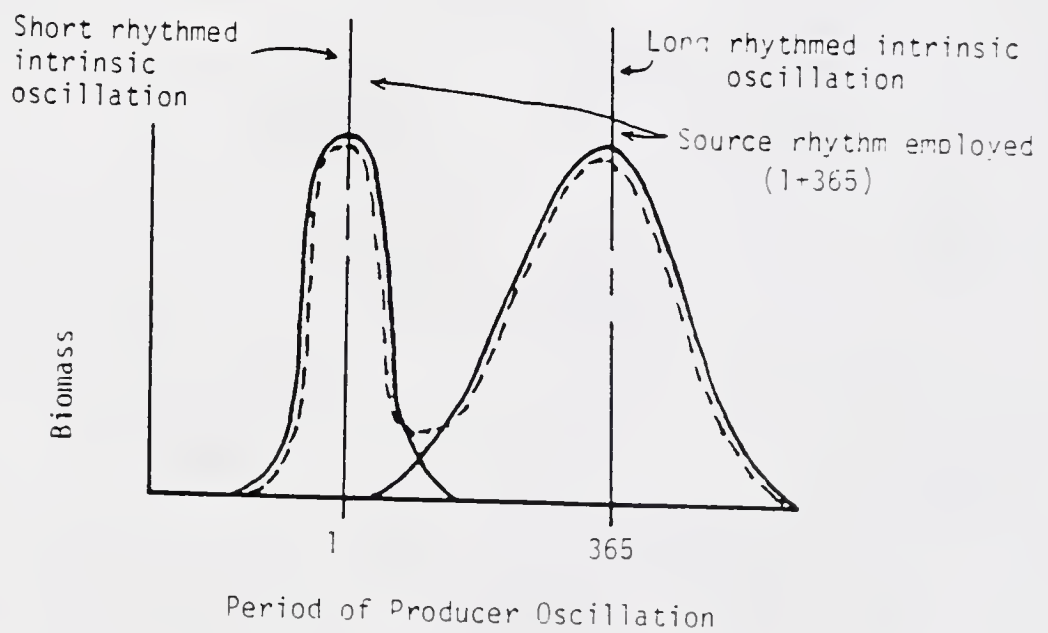
This simulation was completed to analyze the effects on energy-selective competition for producers which develop two or more intrinsic rhythms. The intent of this simulation was to discover if the addition of a second inertial oscillator linked to a second environmental cue provided the producer with a greater competitive advantage.

The diagram in Figure 42a shows the relative period relationships for the system components. The energy-acceptance niche diagram (Figure 42b) shows the relative niches developed as a result the energy-

Figure 42: Simulation 8 system relative period and energy-acceptance niche diagrams (a) system relative periods (b) system relative energy-acceptance niches. The short period producer has a rhythm of 1 day while the long period producer has a rhythm of 1 and 365 days. The source energy is cyclic at a periods of both 1 and 365 days and is therefore cyclic at the intrinsic periods of both producers. The short period rhythm supplies energy of one rhythm to the short period producer. The short and long period rhythms supply energy to the long period producer. The greater energy input for the long period producer makes it a better competitor.



(a)



(b)

selective activity of the competitors. The dashed line represents the relative niche for the dual rhythm producer, and is generated by the combination of its two internal rhythms.

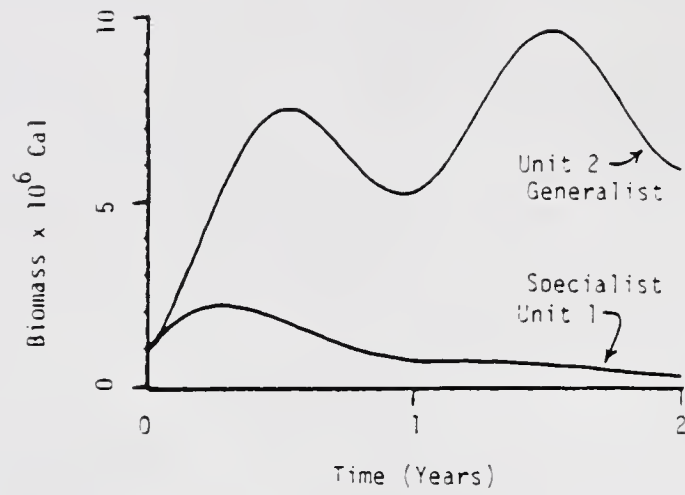
Figure 43a shows the biomass levels for two competing producers. Producer #1 (the specialist) utilizes only one internal inertial oscillator and therefore only one intrinsic behavior pattern. Producer #2 (the complex generalist) uses two internal inertial oscillators and as a result two internal rhythmic behavior patterns. The complex generalist may possess the ability to attract or to link to both fundamental energies of the source.

The source is composed of two fundamental rhythms. The first having a period of 1 day, and the second having a period of 365 days. The figure clearly demonstrates the generalist's competitive advantage, with both fundamental source rhythms appearing in the biomass level of the producer. The specialist, on the other hand, utilizes the shorter period source energy but is competitively excluded by the complex generalist because its single internal rhythmic pattern does not provide an adequate behavior to obtain as much of the available power as does the generalist's dual rhythm internal behavior.

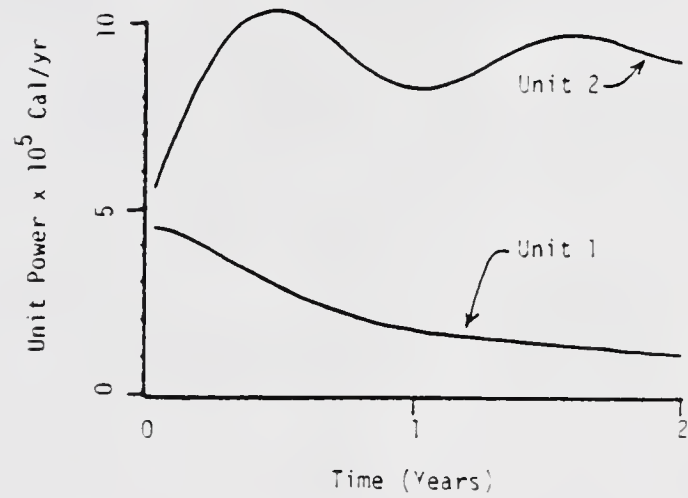
The figure also indicates that early in the competition the specialist increases its biomass slightly. This result, unlike the early success of the one-rhythm generalists in previous simulation sections, may be attributed to the fact that annual intrinsic behavior (from the second inertial oscillator of the generalist) does not produce a significant competitive advantage in early stages of the competition. The control action from the two inertial oscillators of the generalist initially resembles the controlling behavior of the short period

Figure 43: Competition between a complex generalist and a specialist. Plot (a) biomass. Plot (b) unit power. Plot (c) power transfer. The plots indicate the competitive advantage exhibited by a complex generalist. The complex generalist has two internal rhythms, and as a consequence obtains more power, builds greater biomass, and transfers more power than does the specialist. The complex generalist times its environment better than the single rhythm specialist.

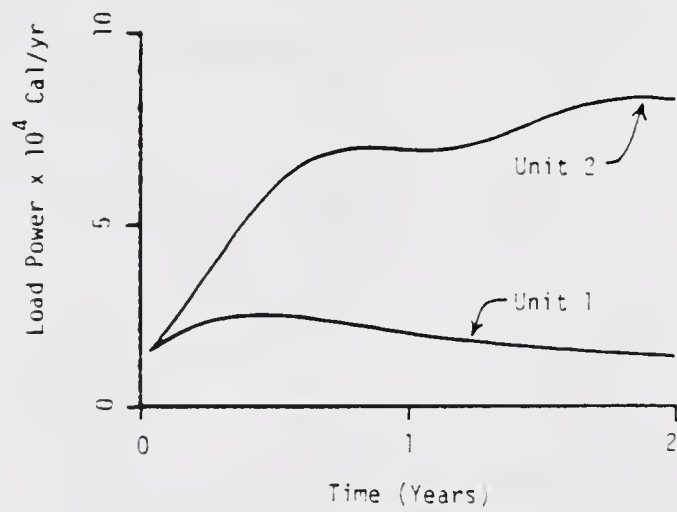
(a)



(b)



(c)



inertial oscillator. Consequently, the two units are competitive equals early in the competition after which time the generalist's annual autocatalytic inertial oscillator (longer rhythmic behavior) provides a competitive advantage that eventually excludes the specialist. Figures 43b and 43c show the unit and load power for the two producers. The unit power obtained from the source by the generalist is the highest initial power of any of the simulations using a dual source rhythmic pattern, but appears to reach a steady state about a mean biomass level approximately equal to that of the specialist in simulation 6. Thus, the combination of short and long term internal behavior provides a competitor with the best competitive advantage insuring survival. Figure 43c indicates that power transfer from the generalist to the system far exceeds that of the specialist.

The advantage offered the system by the dual inertial oscillator producer is its ability to link to both source rhythms or to either fundamental rhythm if one or the other is absent. Thus, the complex generalist is better equipped to deal with source energy that provides energy or energies at rhythms with periods between the two intrinsic patterns of the producer. The timing of two or more rhythms allows the complex generalist to accept energies from a wide range of input. When those inputs are the product of a number of rhythms the complex generalist also possesses the ability to accept energies formed as sideband energies from the interaction. The final analysis indicates that the complex generalist is a formidable competitor.

Models for a Selected Spartina Marsh

The following section contains new simulation plots for a Spartina marsh previously simulated and presented by Odum, Knox, and Campbell,

1983. Additional simulations of the model are presented by Campbell, 1984.

The original mini-model of the Kaituna salt marsh (located in New Zealand) consists of a Spartina townsendii storage, a storage of dead matter as sediment carbon, and a nutrient storage of changeable or labile nitrogen. The two primary energy sources that to determine the growth of Spartina are solar energy (external forcing function) and available nitrogen (internal storage). Two other external sources, tide and river flow, are also part of the model.

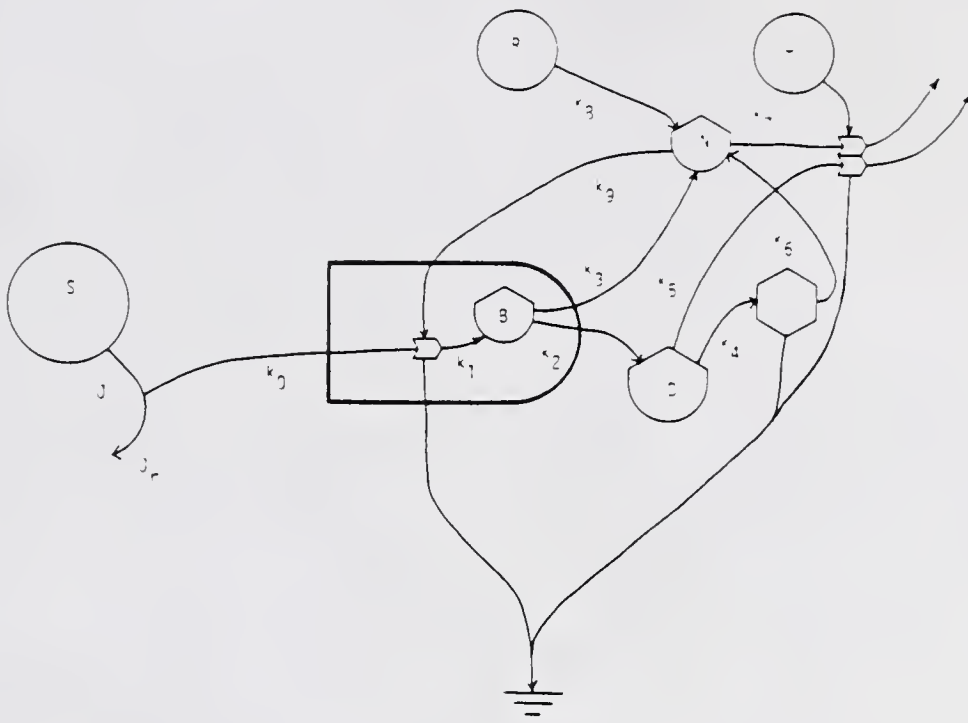
Figure 44 shows the mini-model as originally evaluated (Odum, et al., 1983). Equations 1 through 4 describe the mathematical relationships between the various system components. Table 5 provides the initial flow and storage values from the original model evaluation. The Appendix contains the CSMP computer programs used to simulate the original and five supplemental Kaituna mini-models.

The following eight simulations of the Kaituna mini-model show the effects of the addition of a autocatalytic inertial oscillator to the Spartina townsendii production unit. Each simulation with the exception of the original model use an autocatalytic inertial oscillator as a behavioral control within the Spartina. Simulations 5 and 6 incorporate a second producer unit that is in competition with the Spartina townsendii. Simulations 5 and 6 are therefore theoretical and indicate the effects of energy selective competition within a web system.

Original Kaituna Salt Marsh Mini-model

The intent of this simulation was to duplicate the original simulations for the Kaituna marsh model. The system period

Figure 44: The original Kaituna salt marsh mini-model. The Spartina producer receives solar energy and generates biomass. The biomass is recycled to the nutrient pool which in turn is used to produce more Spartina biomass. A river adds nutrients to the system, while the tidal energy removes nutrients and dead organics from the system. Dead organic material is recycled by the action of consumers within the marsh.



$$J_r = J / (1 + k_0 * N)$$

$$dB/dt = k_1 * J_r * N - k_2 * B - k_3 * B$$

$$dD/dt = k_2 * B - k_4 * D - k_5 * D * T$$

$$dN/dt = k_3 * B + k_4 * k_6 * D + k_3 * R - k_7 * N * T - k_9 * J_r * N$$

Table 5: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Original Kaituna Marsh Model

Component/Storage/Flow	Value	Name or Description	Equation
Sum	3450	$\text{Cal/m}^2/\text{d}$ Solar energy	$3450 + 2250 \sin(\dots)$
B	523	Biomass	$k_1^* J R^* N - k_2^* B - k_3^* B$
D	5226	Dead matter	$k_2^* B - k_4^* D - k_5^* D + I$
N	523	Nutrients	$k_3^* B + k_6^* k_4^* D + k_8^* R - k_7^* I$
f_0	2760	Solar input to producer	$k_0^* J R^* N$
f_1	4.0	Biomass production	$k_1^* J R^* N$
f_2	2.1	Biomass to dead matter	$k_2^* B$
f_3	0.21	Biomass to nutrients	$k_3^* B$
f_4	1.59	Dead matter to consumer	$k_4^* D$
f_5	0.48	Dead matter export	$k_5^* D + I$
f_6	0.29	Conversion dead matter to nutrients	$k_6^* k_4^* D$
f_7	0.09	Nutrient export	$k_7^* N + I$
f_8	0.39	Nutrient import	$k_8^* R$
f_9	0.71	Nutrient uptake in biomass production	$k_9^* J R^* N$
R	4.26e+5	River input	$4.26e+5 + 2.13e+5 \sin(\dots)$
I	1.13e+6	Tide energy	$1.13e+6 + 5.65e+5 \sin(\dots)$

Note: Table for Figure 44.

Figure 45: The system period relationships for the original Kaituna marsh model. The system has a annual source rhythm and the Spartina producer has no internal rhythmic pattern. The system is not energy-selective and the producer does not sense or time its environmental energy source.

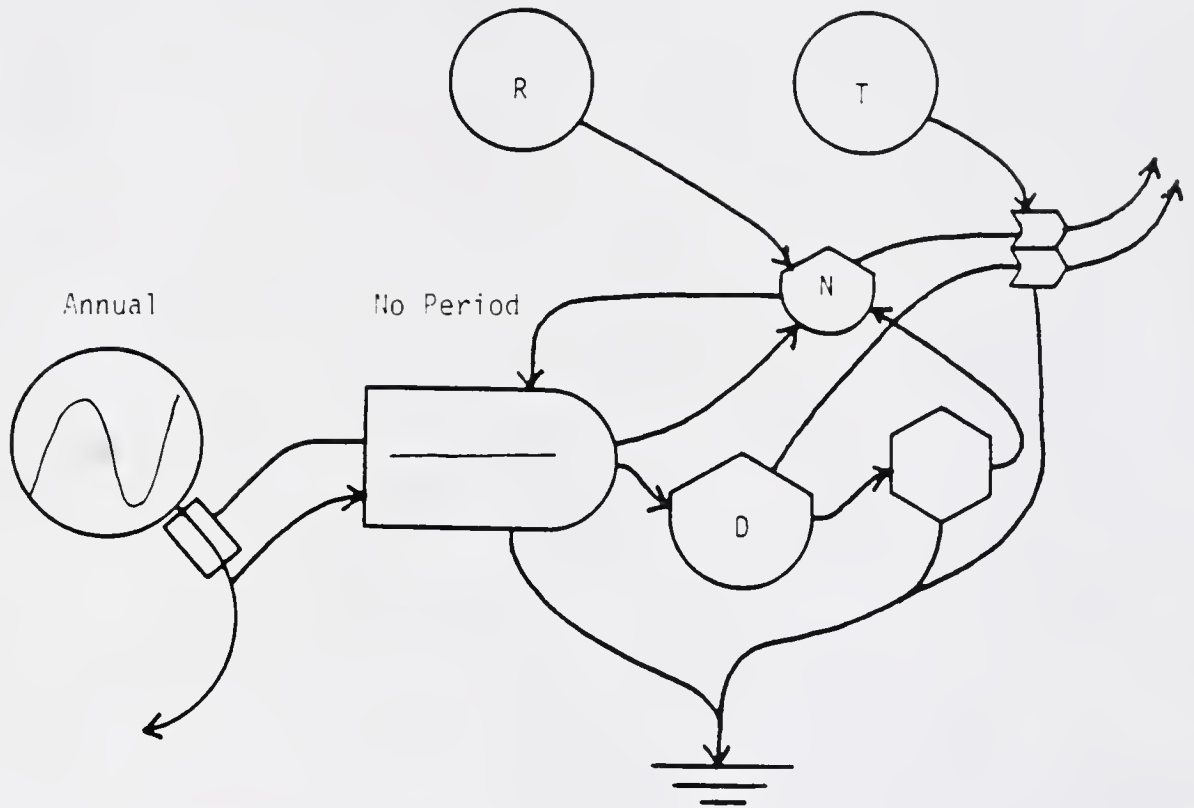
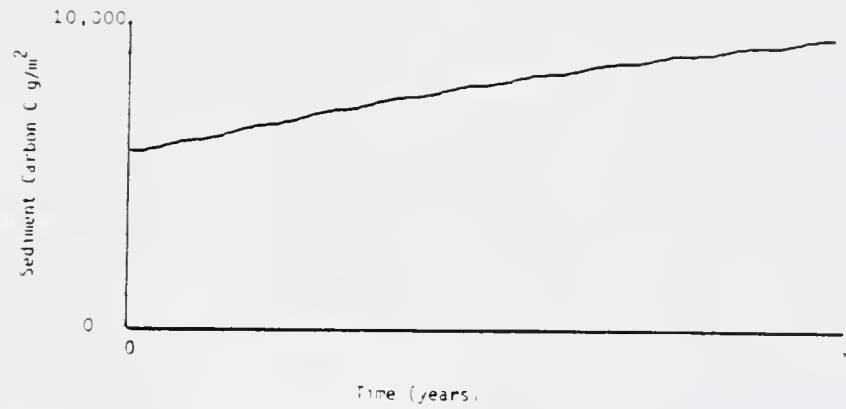
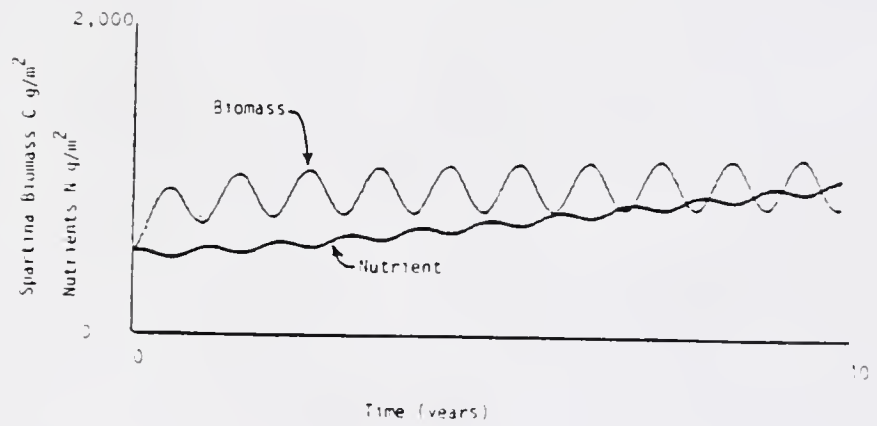


Figure 46: Simulation plots for the original Kaituna salt marsh energy model. Plot (a) dead organic matter. Plot (b) Spartina biomass and system nutrients Plot (c) Spartina unit power. Plot (d) Spartina power transfer. The system produces increased Spartina biomass that exhibits an annual cycle as a result of the solar driving function. Dead matter increases as does the system nutrient pool. The unit input power for the Spartina producer increases rapidly after which time it levels and exhibits an annual pattern of input power. The power transfer for the Spartina module increases more gradually than the input power, however it levels and exhibits a slight annual pattern.

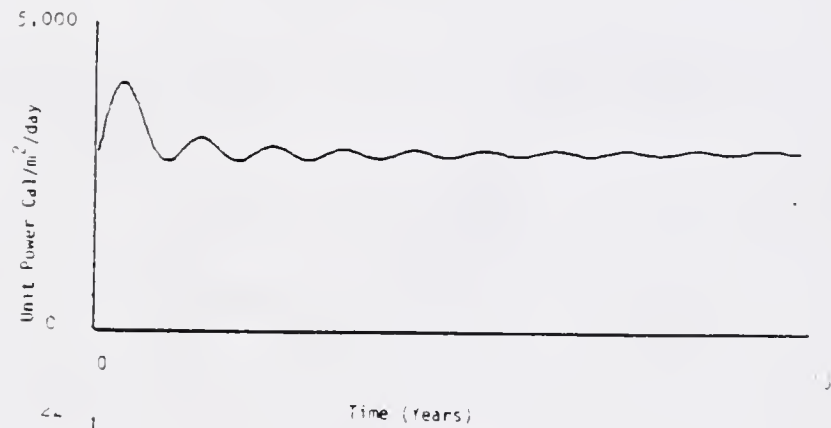
(a)



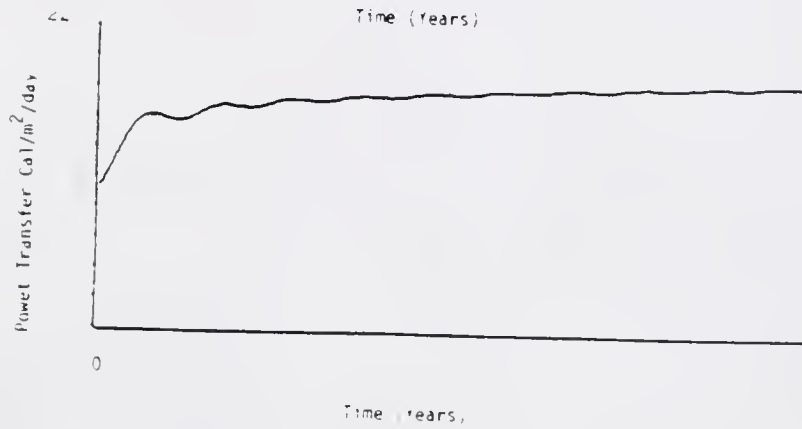
(b)



(c)



(d)



relationships are shown in Figure 45. The source has an annual rhythm and the Spartina producer has no intrinsic rhythmic pattern. Figures 46a and 46b show the levels for the three storages of the Kaituna salt marsh system. With a solar input exhibiting of a annual rhythm, a tidal input with approximately a fortnight rhythm, and a river input with a annual rhythm the system experiences an increase in the level of standing Spartina, dead matter, and labile nitrogen. Although labile nitrogen seems to be the least affected storage--reaching a maximum level of 1000 g N m^{-2} during the 10 year time frame of the simulation. The figures also indicates that Spartina standing stock increases from 523 g C m^{-2} to 1100 g C m^{-2} , while dead matter increases from 5226 g C m^{-2} to 9200 g C m^{-2} .

Figures 46c and 46d show the unit power requirement and power transfer capability of the Spartina producer. The unit power of the Spartina, in solar Calories, acheives an initial maximum power of $3900 \text{ Cal m}^{-2} \text{ day}^{-2}$ thereafter leveling at $3000 \text{ Cal m}^{-2} \text{ day}^{-2}$. The power transfer of the Spartina producer increases gradually to a maximum sustained level of $17 \text{ Cal m}^{-2} \text{ day}^{-2}$.

Kaituna Salt Marsh Mini-model with the Annual Input Solar Energy Rhythm Constructed of a Series of Diurnal Rhythms

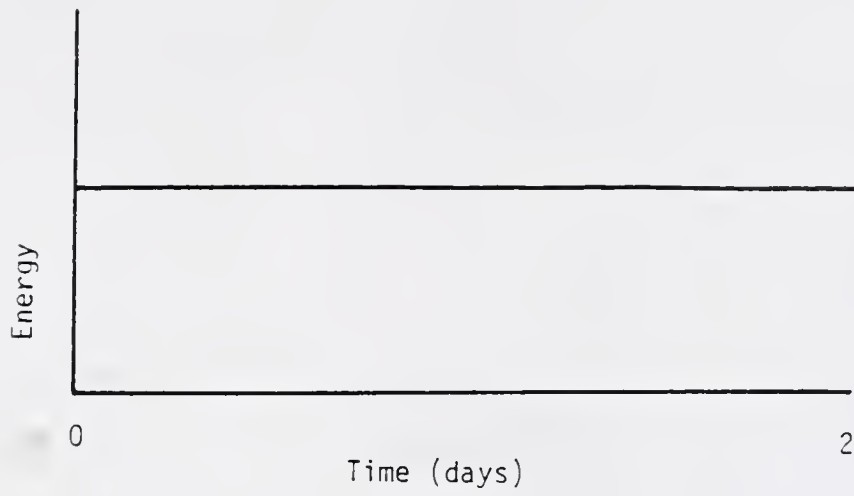
This simulation was employed to introduce a diurnal rhythm into the solar source of the Kaituna model. The original Kaituna mini-model utilizes a solar input energy with an annual rhythmic pattern for its primary external forcing function. The following simulation incorporates into the original solar input a diurnal rhythm, thereby, producing a solar input with a day-night cycle combined within the annual pattern. The new rhythm is necessary because plants and animals

exhibit an internal free-running rhythm that is circadian, approximately 24 hours. Since the power transfer capabilities of energy-selective behavior require an internal free-running oscillation and a comparable external oscillation the Kaituna model was modified to accomodate that requirement. The annual rhythm is supported by an underlying or fundamental diurnal rhythm. Including a diurnal rhythm into the original solar source required that the amplitude and mean level of the original rhythm be divided by 0.3535 (or increased 2.857 times) in order to provide the same amount of energy as the original solar input energy.

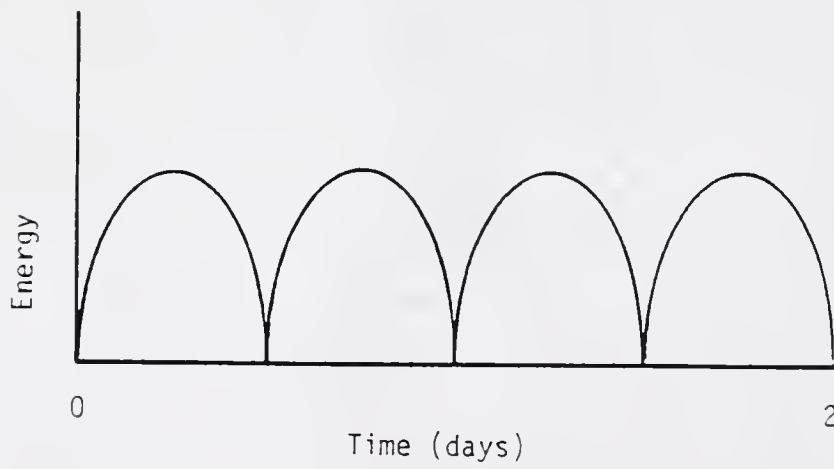
Figure 47 presents a series of diagrams which explain the neccesity for an increase in the amplitude of the new more complex rhythm in order to maintain the same energy input. Essentially the addition of a period of darkness into the new rhythm requires that the source amplitude be increased to account for the loss in energy during darkness. The energy of the new more complex source rhythm, at the same amplitude, is only 35.35% of the energy of the original solar source--without the addition of the diurnal rhythm.

The system period relationships are presented in Figure 48 and indicate that the source contains or supplies energy to the system at both a diurnal and annual rhythm. The Spartina producer however, still contains or produces no intrinsic rhythmic pattern. Figure 49 shows the simulation plots for the three storages within the model. Interestingly, the standing Spartina biomass and the dead matter decreased as a result of the addition of a diurnal rhythm. Their storages reach a maximum of 980 g C m^{-2} and 8250 g C m^{-2} , respectively. Nutrient storage of labile nitrogen remained relatively constant during the simulation as in the previous simulation, reaching a maximum of 975

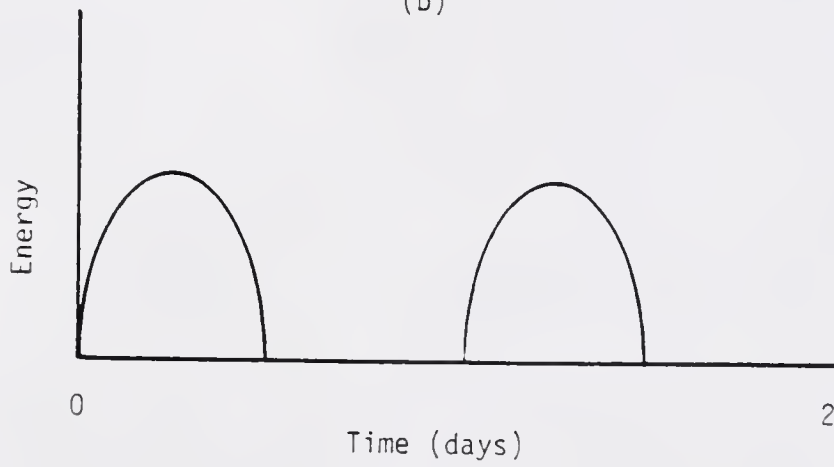
Figure 47: Conversion of average yearly energy input for diurnal energy input: (a) mean energy level, (b) 70.7 percent of the mean energy level in (a), (c) 35.35 percent of the mean energy level in part (a). To insure that the same energy is input by a diurnal rhythm the mean energy level must be increased by 2.8289 times.



(a)



(b)



(c)

Figure 48: The system period relationships for the original Kaituna marsh model modified to include a diurnal rhythm for the available source energy. The system has a annual and diurnal source rhythm and the Spartina producer has no internal rhythmic pattern. The system is not energy-selective and the producer does not sense or time its environmental energy source.

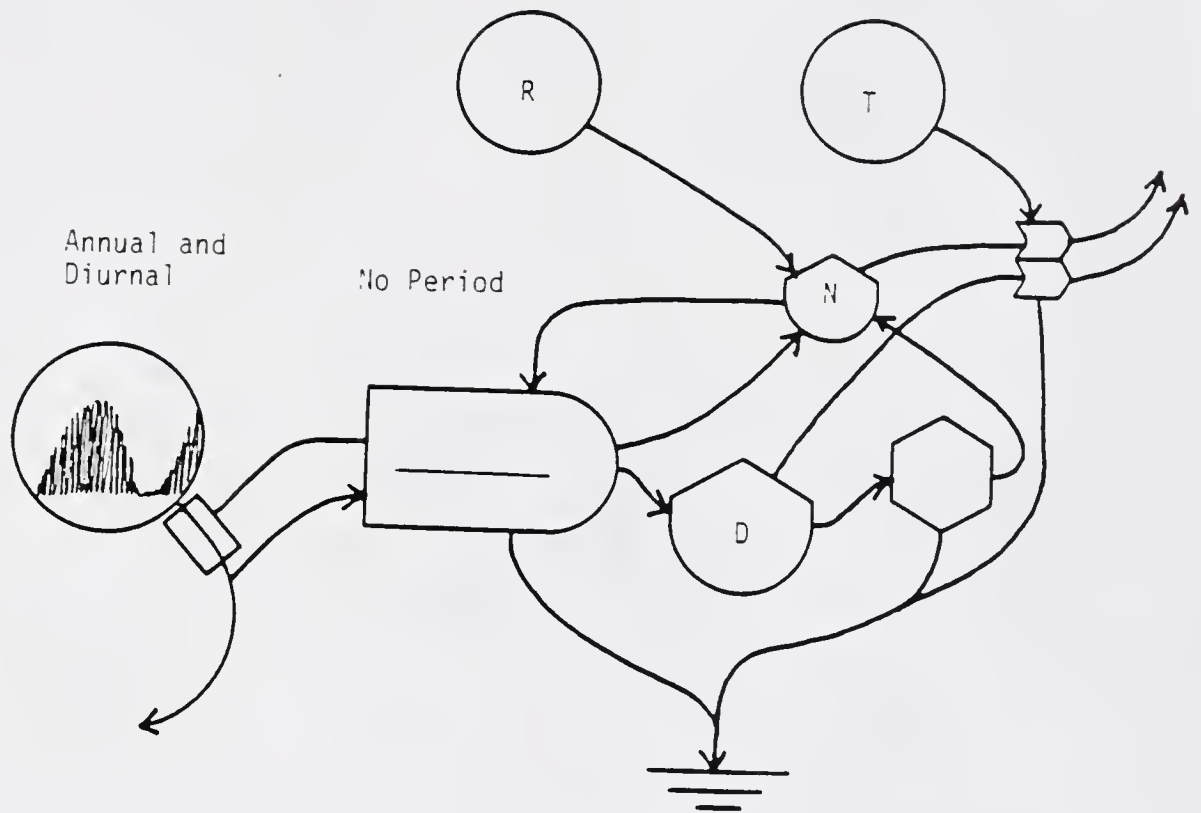
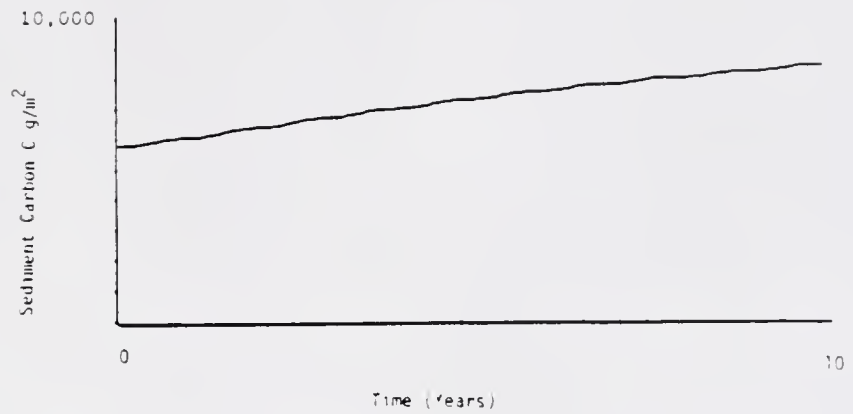
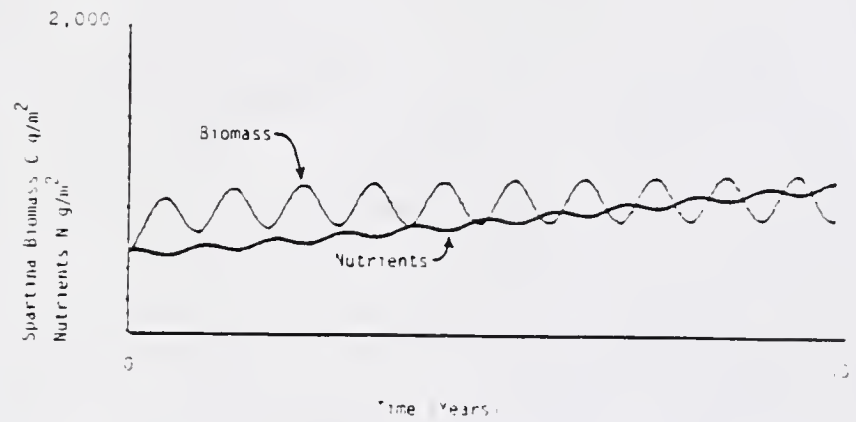


Figure 49: Simulation plots for the Kaituna salt marsh model with the addition of a diurnal solar input. Plot (a) Dead organic matter. Plot (b) Spartina biomass and system nutrient storage. Plot (c) Spartina unit power. Plot (d) Power transfer for the Spartina producer. Dead matter increases but not as rapidly as in the original model. Spartina biomass increases slight but again not as much as in the original model. Nutrient recycle is slower than in the original model, and unit power and power transfer are also decreased.

(a)



(b)



(c)



(d)



-2

g N m . The storage of dead matter shows the greatest change decreasing 10% from its previous level. One explanation for the model's reaction to the addition of the new more rapidly changing rhythm in solar input could be that the Spartina (as modelled and without the guidance of some internal behavioral characteristic) acts as a filter to rapidly cycling energy. Therefore, the solar input energy does not transfer as rapidly to the storage of sediment carbon as in the previous simulation.

All of the following models of the Kaituna marsh incorporate an autocatalytic inertial oscillator into the Spartina producer.

Kaituna Salt Marsh with the Addition of an Autocatalytic Oscillator as an Internal Behavioral Guide for the Spartina Producer

The intent of this simulation was to introduce an autocatalytic Inertial oscillator into the Spartina producer within the Kaituna marsh model. Figure 50a indicates the relative period relationships for the modified Kaituna model. The Spartina producer has an intrinsic diurnal rhythmic pattern and as a result links to that rhythm of the source energy. The relative energy-acceptance niche for the Spartina producer is shown in Figure 50b, and is only intended to provide a visual representation of the energy-acceptance niche. Figure 51 is an energy diagram of the Kaituna salt marsh mini-model including the addition of an autocatalytic inertial oscillator within the Spartina production module. Table 6 indicates the component initial conditions, a description, and the equations for the flows and storages in Figure 40. The biological oscillator produces an internal free-running circadian rhythmic behavioral guide for the Spartina. The intrinsic rhythmic pattern of the oscillator guides the behavior of the Spartina during the

Figure 50: The system relative niche and period relationships for the modified Kaituna marsh model including one energy-selective Spartina producer. The system has a annual and diurnal source rhythm and the Spartina producer has an diurnal internal rhythmic pattern. The system is energy-selective and the producer does sense or time its environmental energy source. Diagram (a) shows the system period relationships and (b) shows the relative energy-acceptance niche for the producer.

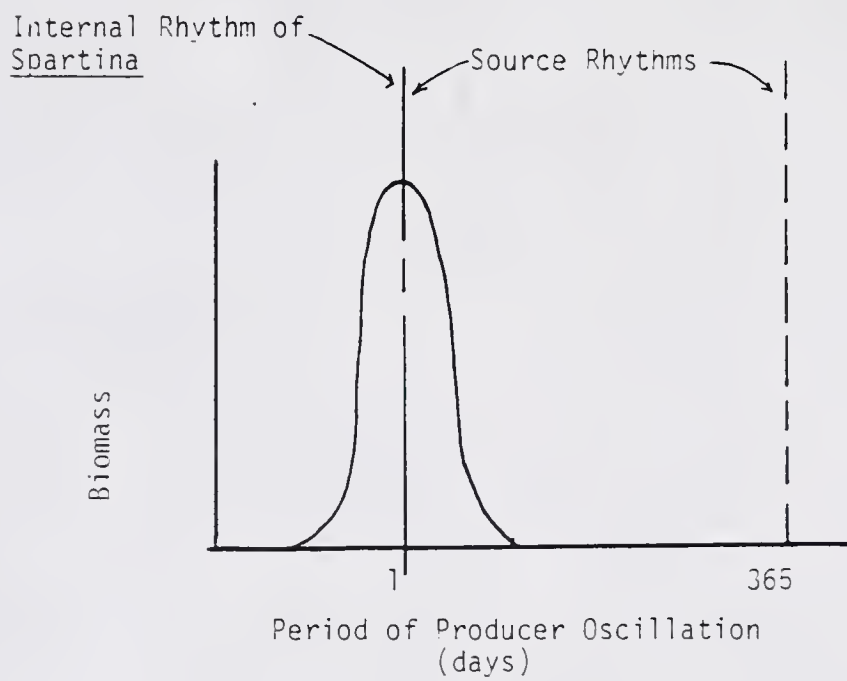
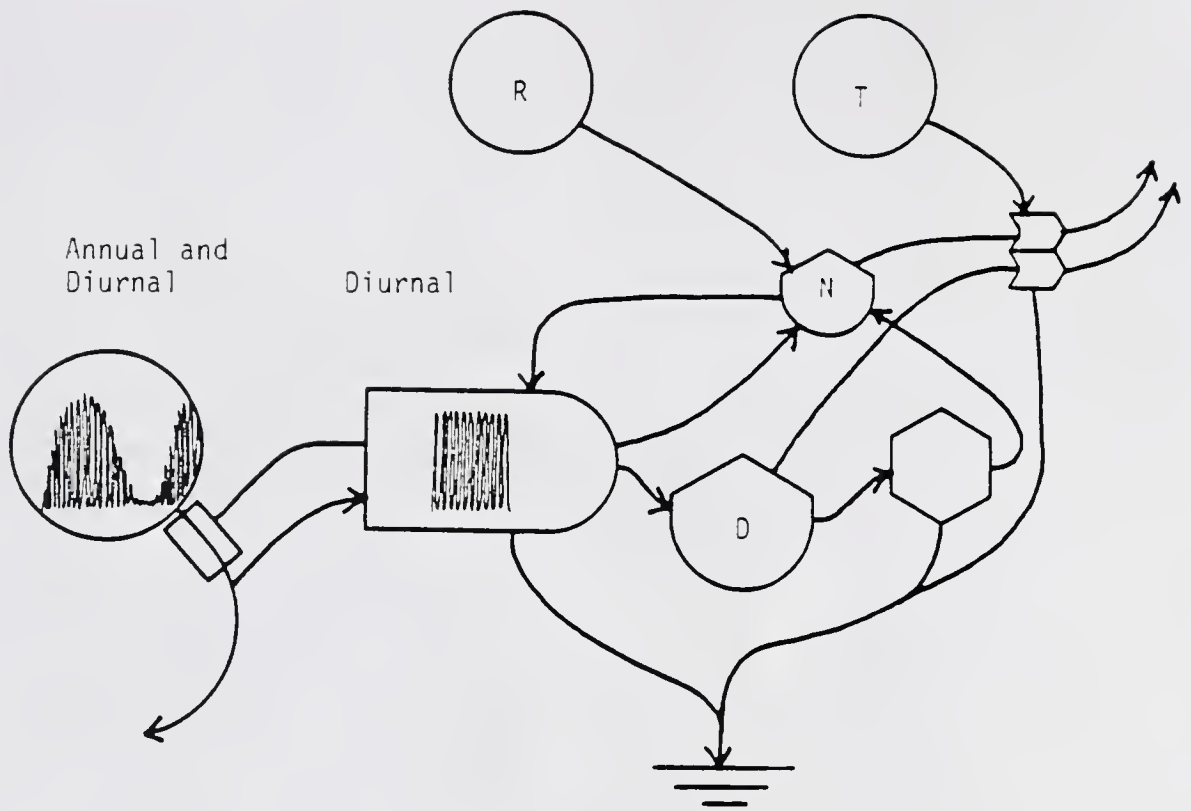


Figure 51: Kaituna marsh model modified by the addition of an energy-selective Spartina producer. The Spartina producer senses the solar input and interacts with that energy source based upon its internal timing ability or behavior to acquire energy. The following plots are a series of simulations using this particular modification of the original Kaituna marsh model. The internal oscillator represents the action of a biological clock.

Table 6: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Modified Kaituna Marsh Model

Component/Storage/Flow	Value	Name or Description	Equation
Sun	3450	$\text{Cal/m}^2/\text{d}$ Solar energy	$3450 + 2250 \sin(\omega_y \cdot t) \cdot S$
B	523	C g/m^2 Biomass	$k_1 \cdot J_r \cdot N - k_2 \cdot B - k_3 \cdot H$
D	5226	C g/m^2 Dead matter	$k_2 \cdot B - k_4 \cdot D - k_5 \cdot I$
N	523	N g/m^2 Nutrients	$k_3 \cdot B + k_6 \cdot k_4 \cdot D + k_8 \cdot R - k_7 \cdot I$
f_0	2760	Cal/m^2 Solar input to producer	$k_0 \cdot J_r \cdot N$
f_1	4.0	C g/m^2 Biomass production	$k_1 \cdot J_r \cdot N$
f_2	2.1	C g/m^2 Biomass to dead matter	$k_2 \cdot B$
f_3	0.21	C g/m^2 Biomass to nutrients	$k_3 \cdot B$
f_4	1.59	C g/m^2 Dead matter to consumer	$k_4 \cdot D$
f_5	0.48	C g/m^2 Dead matter export	$k_5 \cdot D \cdot I$
f_6	0.29	N g/m^2 Conversion dead matter to nutrients	$k_4 \cdot k_6 \cdot D$
f_7	0.09	N g/m^2 Nutrient export	$k_7 \cdot N \cdot I$
f_8	0.39	H g/m^2 Nutrient import	$k_8 \cdot R$
f_9	0.71	N g/m^2 Nutrient uptake in biomass production	$k_9 \cdot J_r \cdot N$
R	4.26e+5	m^3/d River input	$4.261 \cdot 10^5 + 2.131 \cdot 10^5 \cos(\omega_y \cdot t)$
I	1.13e+6	m^3/d Tide energy	$1.131 \cdot 10^6 + 5.651 \cdot 10^5 \sin(\omega_T \cdot t)$

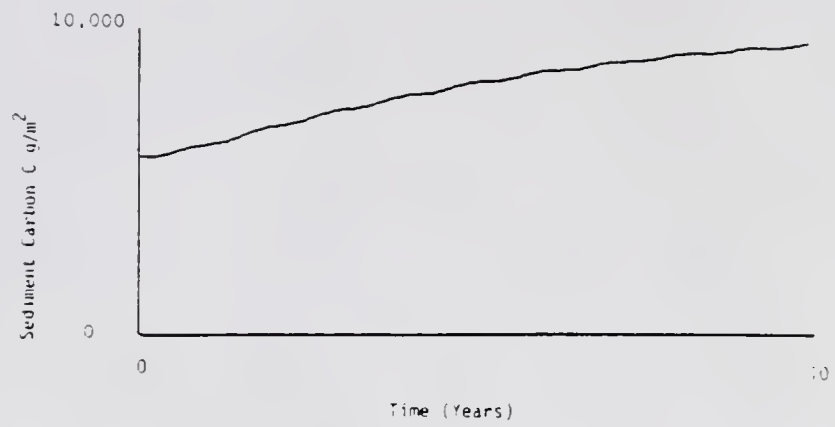
Note: Table for Figure 51.

photosynthetic production of biomass using labile nitrogen as a nutrient pool. No other biological oscillators are included for the model simulation, and all forcing function rhythms are the same ones used for the previous simulations of the marsh.

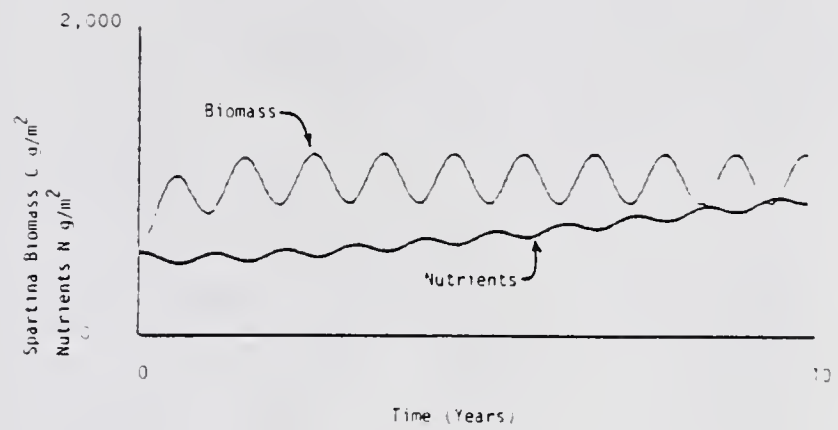
Figures 52a and 52b present the levels for the three marsh storages. Spartina standing biomass increases significantly 1150 g C m^{-2} when compared to the previous simulation 980 g C m^{-2} , and compares more favorable to the level of biomass for the original simulation of the mini-model. Sediment carbon also increases significantly 9200 g C m^{-2} when compared to the previous simulation 8250 g C m^{-2} , and also compares well with the original level for the storage dead matter. Labile nitrogen remains relatively constant decreasing to a level of 900 g N m^{-2} as compared to 1000 g N m^{-2} . Interestingly, the addition of the autocatalytic inertial oscillator, (or the addition of an intrinsic rhythmic behavior) to the new mini-model of the salt marsh compensates for the decreases in biomass and dead matter resulting from the addition of a diurnal solar rhythm to the original model. The result can only be explained as a better coupling between the system and the solar input. Since the model with the new solar input (the day-night pattern supporting an annual rhythm) and no autocatalytic inertial oscillator did not obtain as much solar energy as did the model with the inertial oscillator; the addition of the inertial oscillator must produce a better couple between source and system. This result is a significant indication of the ability of energy-selective units to better couple with sources that supply energies which are cyclic or are cyclic about some mean energy level.

Figure 52: Simulation plots for the modified Kaituna marsh model. Plot (a) Dead organic matter. Plot (b) Spartina biomass and system nutrients. Plot (c) Spartina unit power. Plot (d) Spartina power transfer. Dead matter, and biomass increased to approximately the same level in the original model simulation. The storage of system nutrients increased, however not to the level predicted by the original model. Therefore the recycle of nutrient is slower than for the original simulation. The Spartina unit power and power transfer both exceeded the levels for the original simulation indicating the advantage offered because of energy selective behavior.

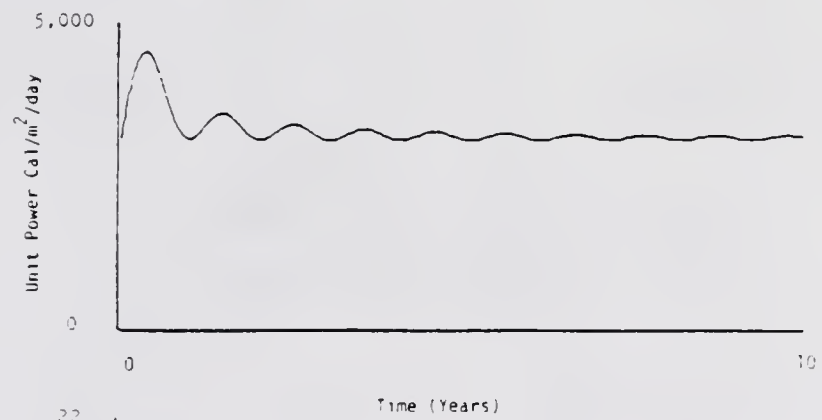
(a)



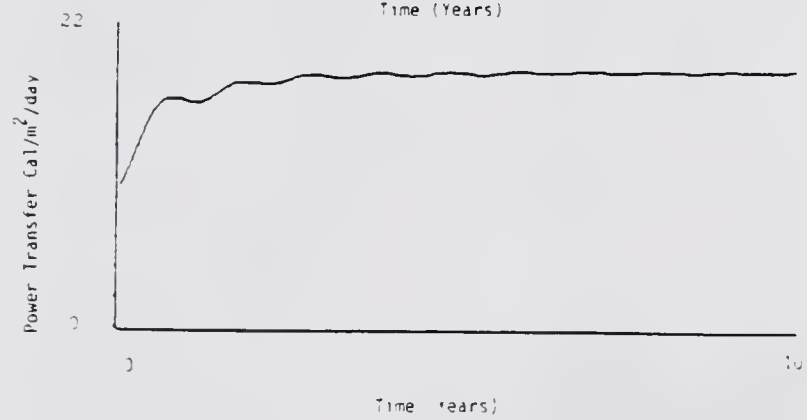
(b)



(c)



(d)

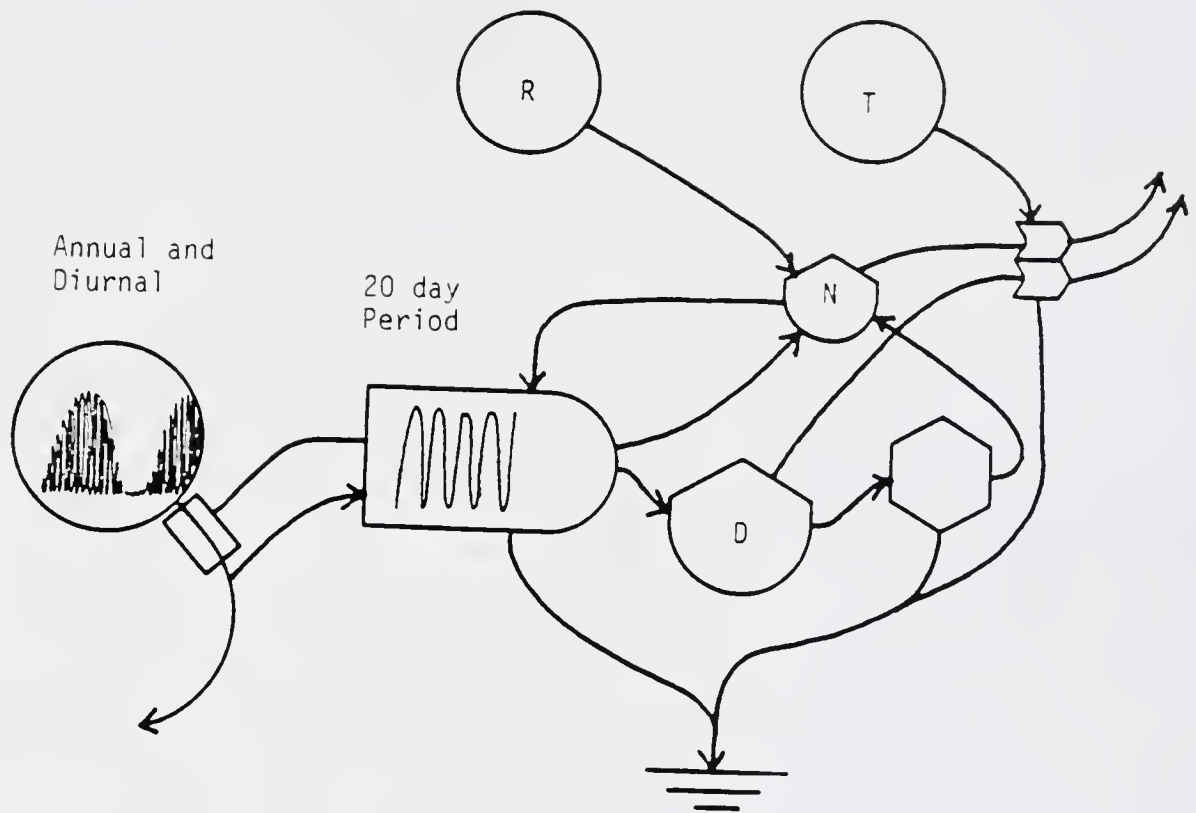


Figures 52c and 52d show the unit power requirement and power transfer capability of the Spartina producer. The unit power of the Spartina, in solar Calories, achieves an initial maximum power of $4500 \text{ Cal m}^{-2} \text{ day}^{-2}$ thereafter leveling at $3400 \text{ Cal m}^{-2} \text{ day}^{-2}$. The power transfer of the Spartina producer increases gradually to a maximum sustained level of $18 \text{ Cal m}^{-2} \text{ day}^{-2}$. The increase in unit power by the addition of the autocatalytic inertial oscillator is 15% above the original models prediction, and the increase in power transfer by the Spartina is 6% above the original model. The simulation clearly indicates that energy selectivity produces a better couple between the producer and the source, and as a result passes on a greater amount of power to the system.

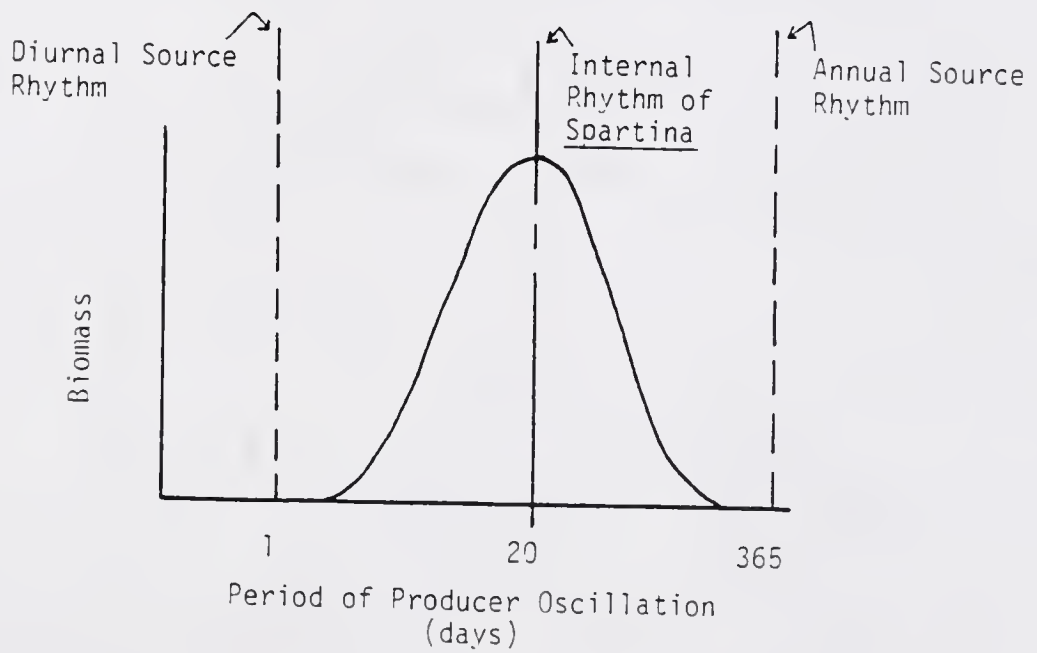
Kaituna Salt Marsh-Mini-model with Spartina Production Module that Uses an Autocatalytic Oscillator Producing a Niche Incapable of Utilizing the Solar Input Energy

This simulation shows the energy-selective property of the Spartina producer as a result of the addition of the autocatalytic inertial oscillator. The system relative period relationships are shown in Figure 53a. The energy-acceptance niche for the producer is shown in Figure 53b. The figure also indicates that the two rhythms of the source are not at the same period as is the intrinsic oscillation of the producer. Figure 54 shows the effect on the salt marsh's storages as a result of changing the Spartina's internal free-running behavioral characteristics. The model is identical to the previous simulation model with the exception of the period for the autocatalytic inertial oscillator's internal rhythm. The oscillator's rhythm during the previous simulation linked exactly with the diurnal rhythm of the solar

Figure 53: The system relative niche and period relationships for the modified Kaituna marsh model including one energy-selective Spartina producer. The system has a annual and diurnal source rhythm and the Spartina producer has an 20 day internal rhythmic pattern. The system is energy-selective and the producer does sense or time its environmental energy source. The producer rhythm employed for this simulation does not allow the unit to acquire available source energy and therefore the unit does not survive. Diagram (a) shows the system period relationships and (b) shows the relative energy-acceptance niche for the producer.



(a)



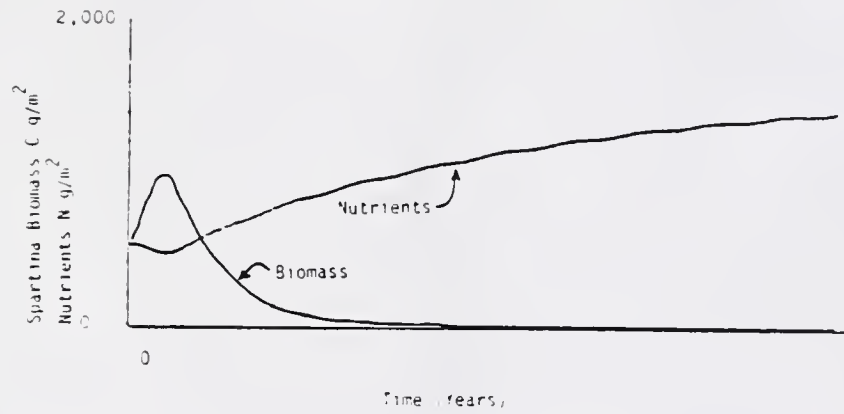
(b)

Figure 54: Simulation plots for Spartina producer with an energy acceptance niche incapable of utilizing solar energy. Plot (a) Dead matter. Plot (b) Spartina biomass. Plot (c) Unit power for the Spartina producer. Plot (d) Spartina power transfer. Dead matter, biomass, unit power, and power transfer all decrease when compared with the original simulation. Nutrient storage within the system increases because the consumers recycle dead matter into nutrients faster than dead matter is replaced. The system and the individual do not survive. The rejection of input energy by Spartina reduces input power and power transfer thereby eliminating the system.

(a)



(b)



(c)



(d)



energy input, however the new inertial oscillator rhythm is 20 times as long as the previous rhythm.

The plots in Figure 54 clearly indicate that if Spartina's internal rhythm were elongated to 20 days, instead of 1 day, the producer could not obtain adequate solar energy to support itself or the remainder of the system. Spartina standing biomass rapidly diminishes and is converted to sediment carbon/dead matter. The storage of dead matter in turn rapidly decreases to a level of 1000 g C m^{-2} and is in turn converted by consumer action to system nutrients. The nutrient nitrogen storage increase because consumers are adding to its storage while the inadequate behavioral activity of the producer decreases its demand for the uptake of nutrients. As a consequence the system stores nitrogen and the storage reaches a maximum level of 7000 g N m^{-2} .

Figures 54c and 54d indicate that the power demand by the Spartina decreases as a result of an inadequate niche to a level of $700 \text{ Cal m}^{-2} \text{ day}^{-1}$. Power transfer from the Spartina producer to the remainder of the system decreases to a level of $2.2 \text{ Cal m}^{-2} \text{ day}^{-1}$.

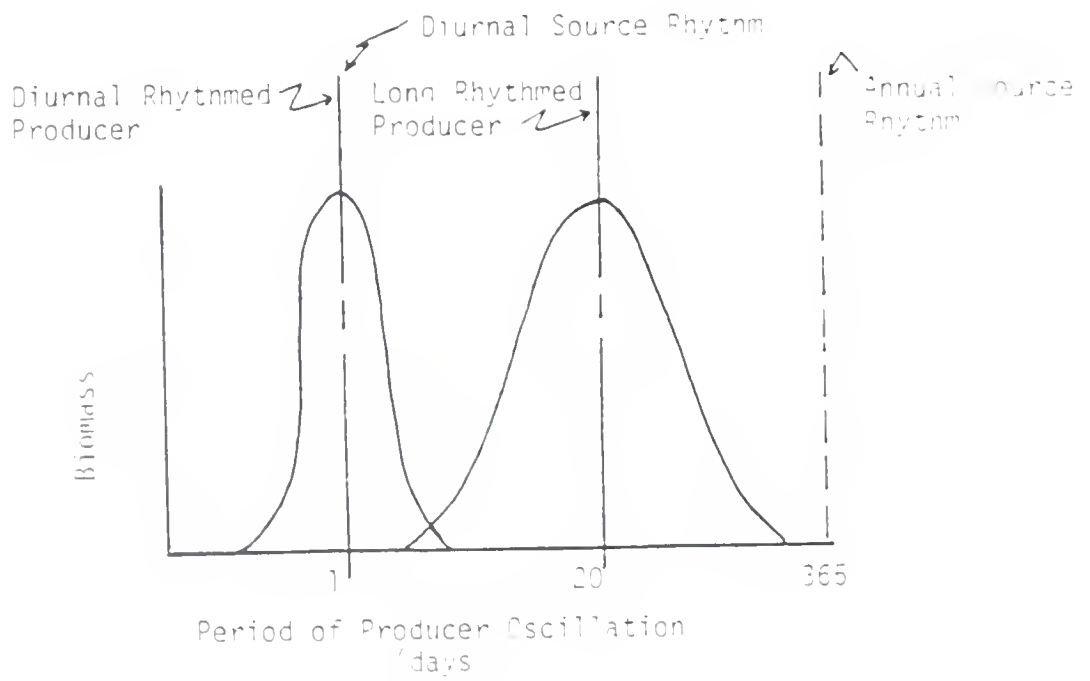
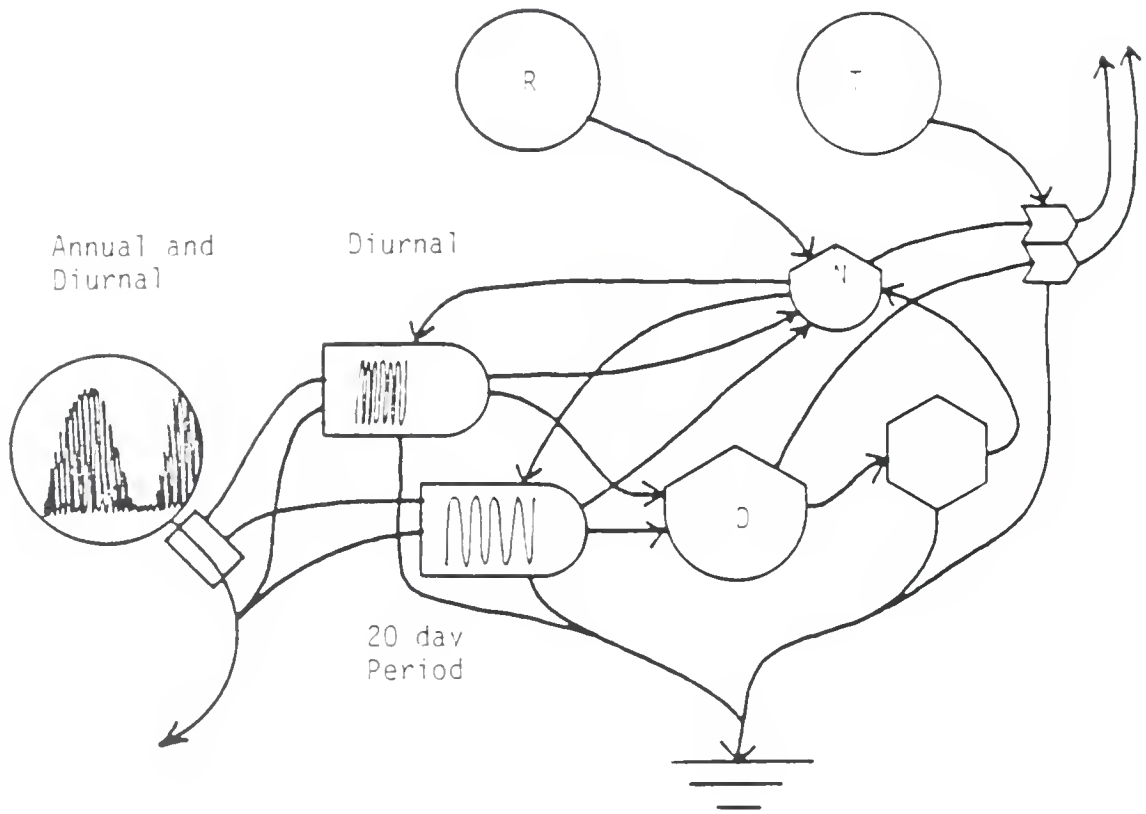
Within the model the system relies upon the Spartina producer for its sustenance and therefore the system vanishes. In reality one would expect some other producer to fill the niche vacated by the Spartina, but the model does not incorporate that concept into the simulation.

The following models address the replacement concept via consideration of energy-selective competition within the Kaituna web.

Kaituna Salt Marsh Mini-model with Competitive Exclusion of a Producer with an Inadequate Niche

This simulation introduces energy-selective competition into the Kaituna marsh web with the intent of analyzing this concept in a web system. The system period relationships are presented in Figure 55a.

Figure 55: The system relative niche and period relationships for the modified Kaituna marsh model including two energy-selective producers in a competition for available solar energy. The system has a annual and diurnal source rhythm and the producers have a diurnal and 20 day internal rhythmic pattern, respectively. The system is energy-selective and the producers do sense or time the environmental energy source. The short period producer's rhythm links with the available energy rhythm and as a result the short period producer is more competitive than the long period producer. The competition proceeds to exclusion of the long period producer. Diagram (a) shows the relative system periods (b) shows the relative energy-acceptance niches.

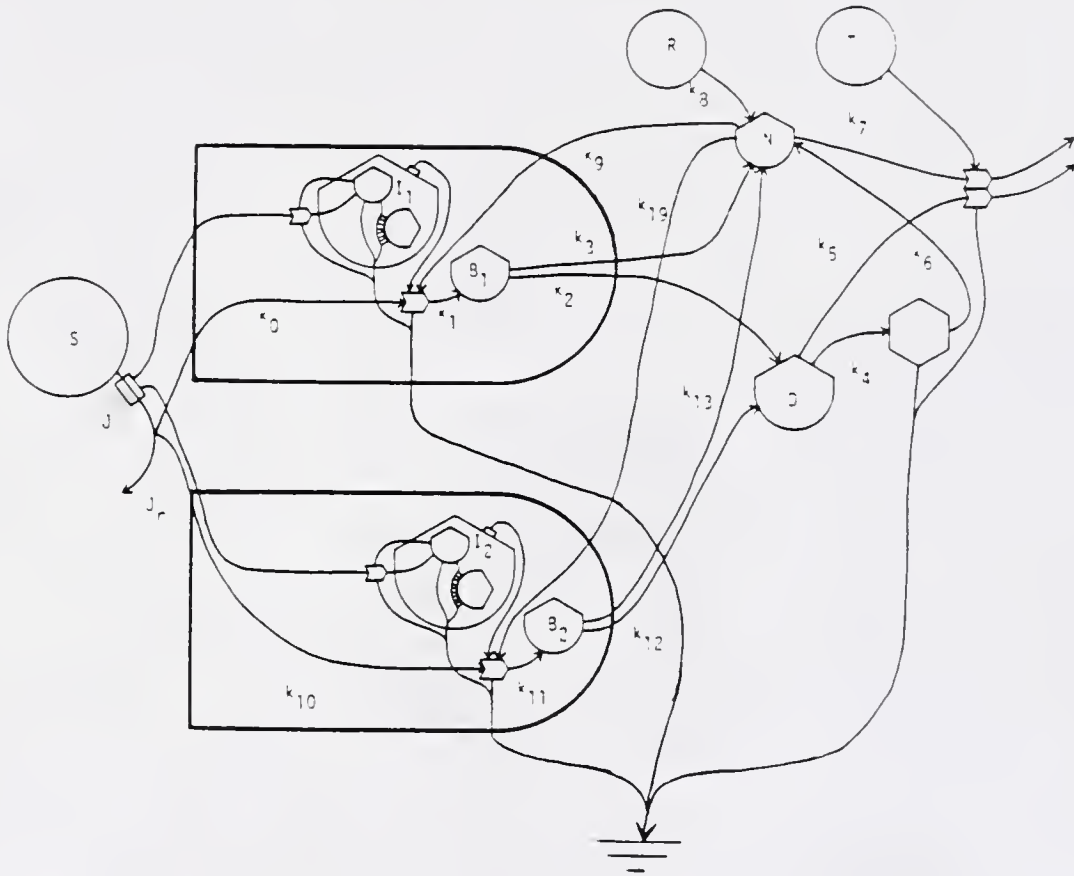


The long rhythm producer clearly generates a rhythm that is not linked to either source rhythm, while the short rhythm producer links to the diurnal rhythm of the source. Figure 55b shows the energy-acceptance niches for both producers.

Figure 56 is an energy diagram of the competition modified mini-model for the Kaituna salt marsh. The model consists of two competing producers. The only difference between the two competitors is their internal rhythmic behavior. Spartina townsendii, unit #1, has an internal circadian period for a behavioral rhythm. Producer #2, a substitute unit for investigative purposes, has an internal behavioral rhythm with a period of 20 days. No input energy with a period of 20 days is available to the system. The solar input supply energy has a diurnal support rhythm which is supplied to both producers. The internal rhythm of Spartina provides it with a better linkage to the solar source energy and is therefore used by the Spartina to exclude its competition.

Figures 57a through 57d clearly show the competitive advantage of the Spartina's behavior. While its competitor is only obtaining solar energy for small portions of the day Spartina's behavior allows it to capture solar energy during the entire daylight hours. As a result, Spartina's standing biomass level increases to a mean of 1000 g C m^{-2} while its competitor's biomass level diminishes. The maximum biomass level obtained by the Spartina producer is 1150 g C m^{-2} and this occurs during the fourth year of the simulation. After the fourth year Spartina's biomass follows an annual pattern about its mean level until the end of the 10 year simulation. The sediment carbon/dead matter in the system increases reaching a maximum level of 9500 g C m^{-2} .

Figure 56: Kaituna marsh model modified to include competitive producer. The system biomass is evenly split between the competitors.



$$J_r = J / (1 + k_0 I_1 N + k_{10} I_2 N)$$

$$dB_1/dt = k_1 I_1 N J_r - k_2 B_1 - k_3 B_1$$

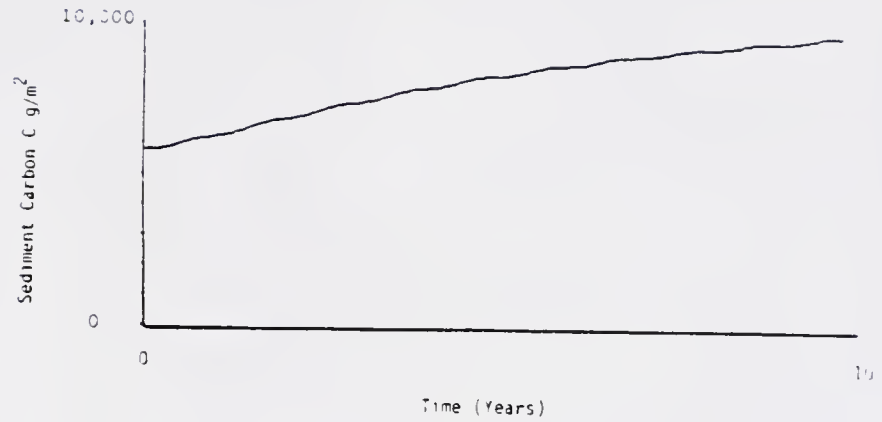
$$dB_2/dt = k_{11} I_2 N J_r - k_{12} B_2 - k_{13} B_2$$

$$dD/dt = k_2 B_1 + k_{12} B_2 - k_4 D - k_5 DT$$

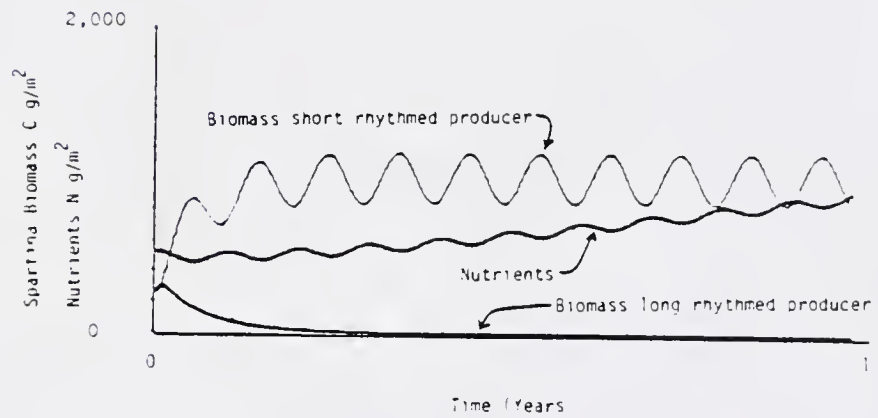
$$dN/dt = k_3 B_1 + k_4 k_6 D + k_8 R + k_{13} B_2 - k_7 NT$$

Figure 57: Plots for modified Kaituna marsh model with competitive exclusion of a producer with an inadequate energy acceptance niche. Plot (a) sediment carbon. Plot (b) biomass and nutrients. Plot (c) unit power for competitors. Plot (d) power transfer for the competitors. The plots clearly indicate the competitive advantage afforded the producer with the acceptance niche period closest to the source energy's period.

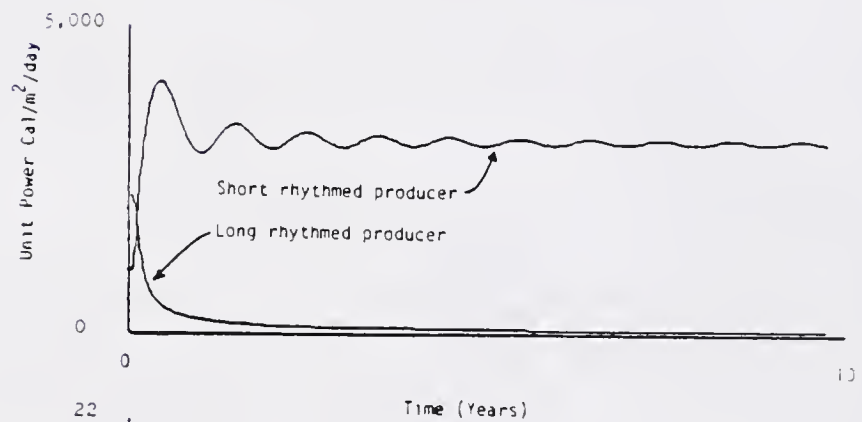
(a)



(b)



(c)



(d)

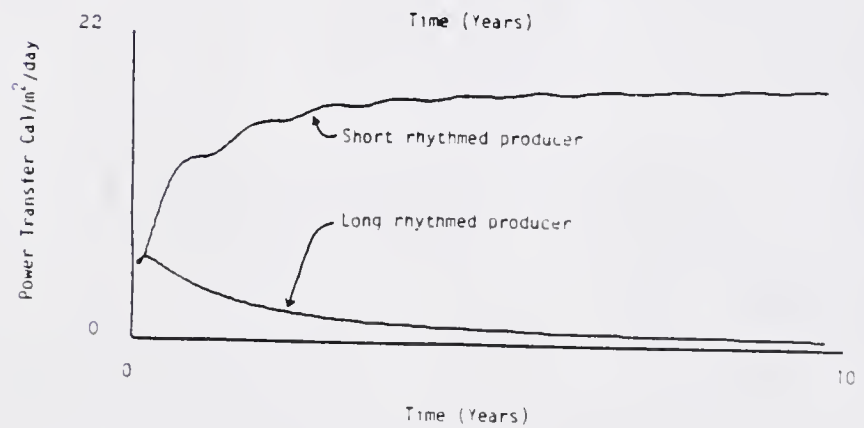


Table 7: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Kaituna Marsh Competition Model

Component/Storage/Flow	Value	Name or Description	Equation
Sun	3450	Solar energy	$3450 + 2250 \cdot \sin(\omega_y \cdot t) \cdot S$
S	-	-	$\sin(\omega_d \cdot t)$ if $qt \neq 0$ else 0
B ₁	261.5	Biomass unit #1	$k_1 \cdot J_r \cdot I_1 \cdot N - k_2 \cdot B_1 - k_3 \cdot B_1$
B ₂	261.5	Biomass unit #2	$k_{11} \cdot J_r \cdot I_2 \cdot N - k_{12} \cdot B_2 - k_{13} \cdot B_2$
D	5226	Dead matter	$k_2 \cdot B_1 + k_{12} \cdot B_2 - k_4 \cdot D - k_5 \cdot D \cdot I$
N	523	Nutrients	$k_3 \cdot B_1 + k_{13} \cdot B_2 + k_4 \cdot D + k_5 \cdot D \cdot I - k_7 \cdot T - k_9 \cdot J_r \cdot I_1 \cdot N - k_{19} \cdot J_r \cdot I_2 \cdot N$
R	4.26E+5	River input	$4.26E+5 + 2.13E+5 \cdot \cos(\omega_y \cdot t)$
T	1.13E+6	Tide energy	$1.13E+4 + 5.65E+5 \cdot \sin(\omega_T \cdot t)$
f ₀	1380	Solar input to producer	$k_0 \cdot J_r \cdot I_1 \cdot N$
f ₁	2.0	Biomass production #1	$k_1 \cdot J_r \cdot I_1 \cdot N$
f ₂	1.05	Biomass to dead matter	$k_2 \cdot J_r \cdot I_1 \cdot N$
f ₃	0.105	Biomass to nutrients	$k_3 \cdot B_1$
f ₄	1.59	Dead matter to consumer	$k_4 \cdot D$
f ₅	0.48	Dead matter export	$k_5 \cdot D \cdot I$
f ₆	0.29	Conversion dead matter to nutrients	$k_6 \cdot k_4 \cdot D$
f ₇	0.09	Nutrient export	$k_7 \cdot N \cdot I$
f ₈	0.39	Nutrient import	$k_8 \cdot R$
f ₉	0.365	Nutrient uptake #1	$k_9 \cdot J_r \cdot I_1 \cdot N$
f ₁₀		Same as f ₉	$k_{10} \cdot J_r \cdot I_2 \cdot N$
f ₁₁		Same as f ₉	$k_{11} \cdot J_r \cdot I_2 \cdot N$
f ₁₂		Same as f ₉	$k_{12} \cdot B_2$
f ₁₃		Same as f ₉	$k_{13} \cdot B_2$
f ₁₉		Same as f ₉	$k_{19} \cdot J_r \cdot I_2 \cdot N$

Note: Table for Figure 56.

Comparison of the simulation plots indicates that the competition between the Spartina and its longer rhythmed competitor is relatively none existent. In fact the system as a whole reached approximately the same levels for standing biomass, dead matter, and nutrients as is achieved without competition. This result may be explained by the reluctance of the long rhythmed producer's to provide any real competition with the Spartina. Since the longer rhythmed producer could or would not capture solar input with the same efficiency that the Spartina captures the energy the competition ends quickly and produces little or no stress on the Spartina.

Table 7 shows the distribution of biomass and flows for the addition of the competing producer. The system biomass and solar input energy is shared between the producers to start the simulation. Pathway flows to the storages of sediment carbon and labile nitrogen are halved to maintain the same system input to the storages. Therefore, the model incorporates a new competitive unit without disturbing the initial sense of the system.

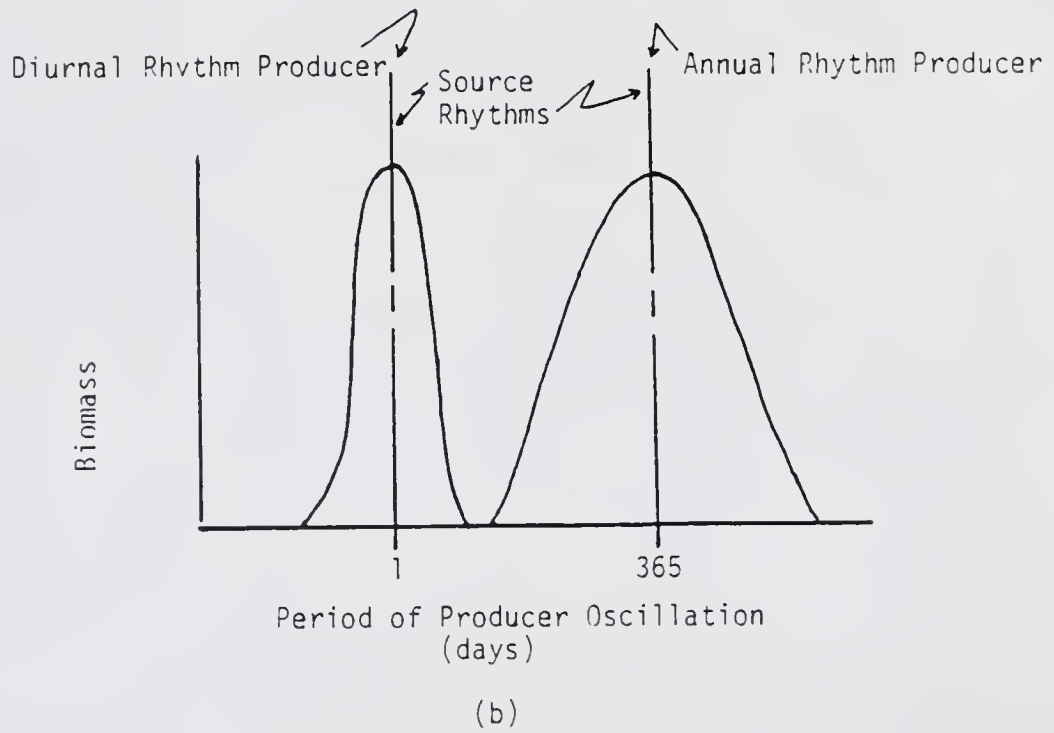
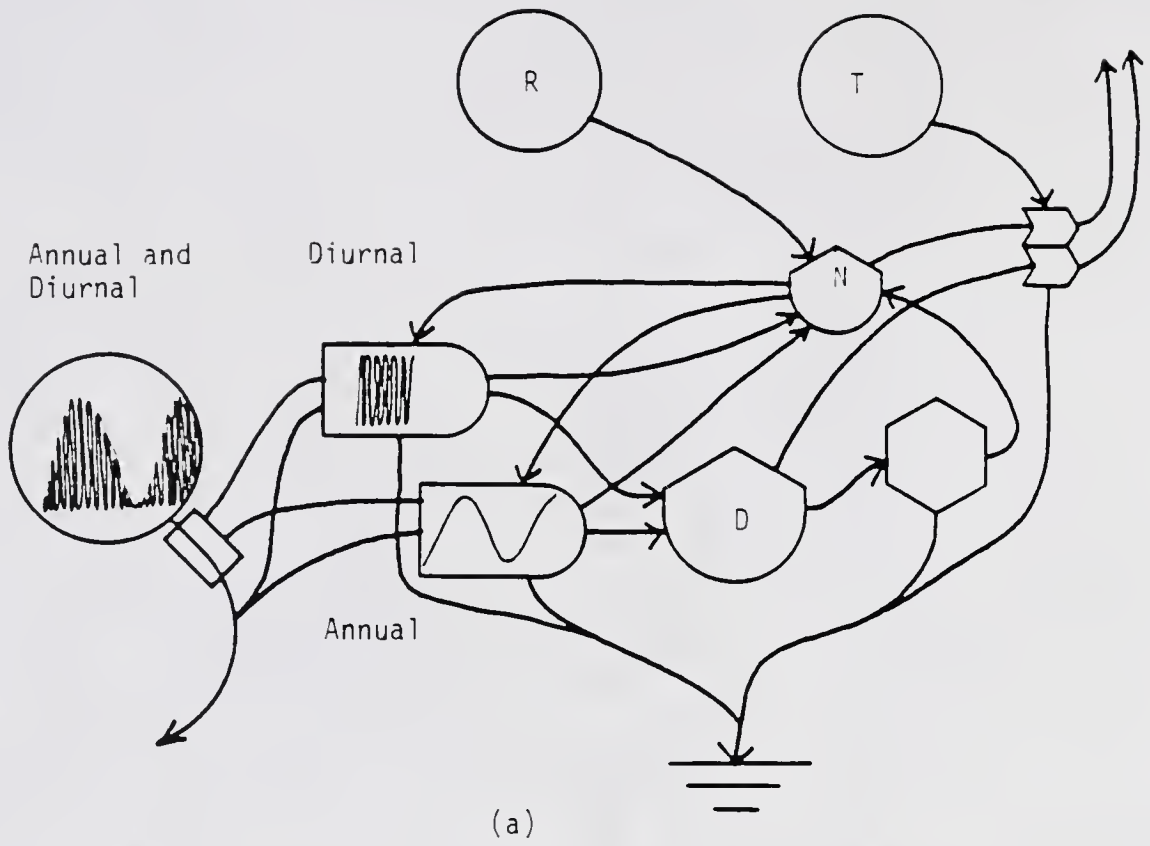
Kaituna Salt Marsh Modified Mini-model to Include Competition Between Producers with the Ability to Obtain Solar Energy at Different Rhythms

The competition model used for this simulation is the same model used for the previous simulation, however the period of the long rhythmed competitor (producer #2) is increased to 365 days. This simulation was employed to investigate the effects of competition between two competitors that utilize different fundamental rhythms from the same source. In the competition section that employed hypothetical producers this concept was analyzed and indicated that the short rhythm competitor should outcompete the long rhythmed competitor. This

simulation expands that concept into web systems in an attempt to discover if web feedback has an effect on the competition. Figure 58a shows the system period relationships for the model simulated. Source energy is composed of two rhythms one a circadian rhythm and the other a circannual rhythm. The acceptance niches for the two competitors are shown in Figure 58b.

Figures 59a and 59b show the levels for the four storages of the salt marsh (Spartina biomass, labile nitrogen, sediment carbon, and the storage of biomass for the longer rhythm producer). Initially the Spartina with the circadian internal rhythm outcompetes the unit with the internal annual behavior pattern, and reaches a maximum standing biomass of 1050 g C m^{-2} at time equal 3 years in the simulation. The long rhythm (365 day) competitor outcompetes the short rhythm producer during the middle years of the simulation reaching a maximum biomass level of 800 g C m^{-2} at time equal 6 years in the simulation. However, the Spartina again regains its dominant posture at time equal 8 years. The simulation indicates that the two producers coexist thereafter but with slightly less total system biomass. The summation of the two producers' biomass indicates that system biomass level at a mean of 1000 g C m^{-2} . Dead matter within the system increases and reaches a maximum level of 9800 g C m^{-2} --approximately equal to the level obtained during the previous simulation. Nutrient storage within the system remained relatively constant at 950 g N m^{-2} as in the previous five simulations. The competition produces a system in which the short rhythm Spartina townsendii dominates for the majority of the time. The system has more diversity while maintaining approximately the same level of dead matter and nutrient storage.

Figure 58: The system relative niche and period relationships for the modified Kaituna marsh model including two energy-selective producers in a competition for available solar energy. The system has a annual and diurnal source rhythm and the producers have a diurnal and annual internal rhythmic pattern, respectively. The system is energy-selective and the producers do sense or time the environmental energy source. The short period producer's rhythm links with the available energy rhythm as does the long period producer. The web feedback effect provides long period feedback from the system and as a result the long period producer is more competitive and coexistence is established between the two producers. Diagram (a) shows the relative system periods (b) shows the relative energy-acceptance niches.



Figures 59c and 59d show the power requirements for the two competitors, as well as, their power transfer to the remainder of the system. The unit power for the two competitors indicates that the Spartina producers acquires the greatest amount of input power reaching a steady state level of $2500 \text{ Cal m}^{-2} \text{ day}^{-1}$. The plot also indicates that the total system input power from the solar source remains approximately the same at $3700 \text{ Cal m}^{-2} \text{ day}^{-1}$.

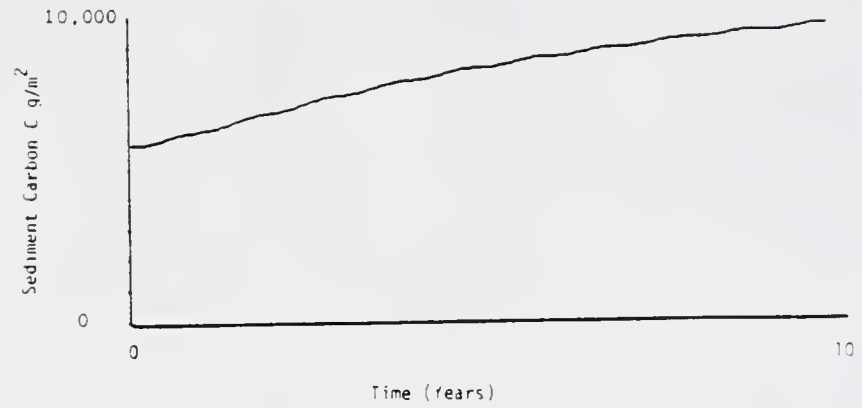
Summation of the power transfer for both producers indicates that the total power transfer to the rest of the system is $19 \text{ Cal m}^{-2} \text{ day}^{-1}$, and that the Spartina producer transfers the largest amount of the two units.

Remembering that the competition simulation plots for energies from the same quality source in the previous section utilized no feedback from other components in the system provides insight into the competitive coexistence that is shown in the plots in Figure 45. Since the longer period annual rhythm of the input solar energy is from the same energy quality source as is the diurnal rhythm energy, and since the longer period producer coexists with the Spartina producer; it appears that long period competitive success at the bottom of the food chain requires the feedback of a longer period rhythm from a component within the system--or for that matter from a component within the next higher system. The annual rhythm of the nutrient storage provides that longer rhythm feedback for this simulation. The nutrient storage acquires an annual rhythm via the nutrient input from the river source and from the input from the Spartina producer.

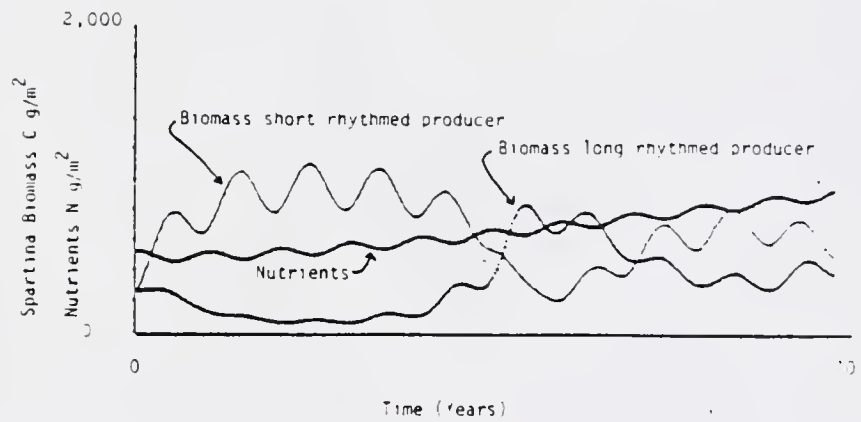
Odum 1983, indicates that there is an advantage to control provided by long-period feedback from components in or out of the system

Figure 59: Plots of competition between producers in the Kaituna marsh that obtain energies at different frequencies from the same energy quality source. Plot (a) dead matter. Plot (b) biomass and system nutrients. Plot (c) unit power for the two competitors. Plot (d) power transfer for the competitors. The plot indicates a coexistence between competitors.

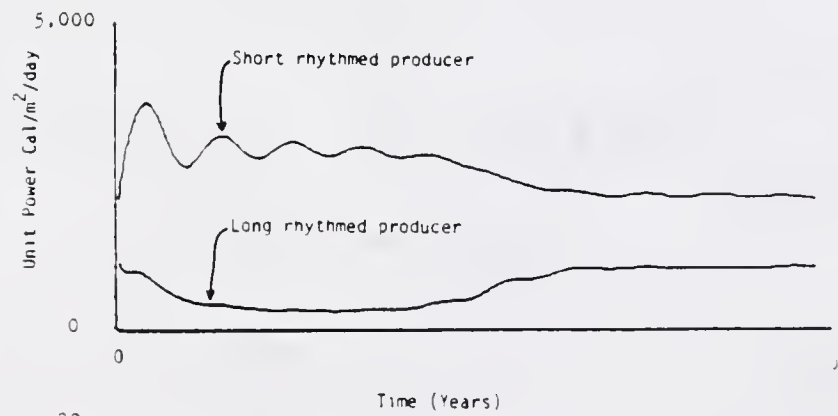
(a)



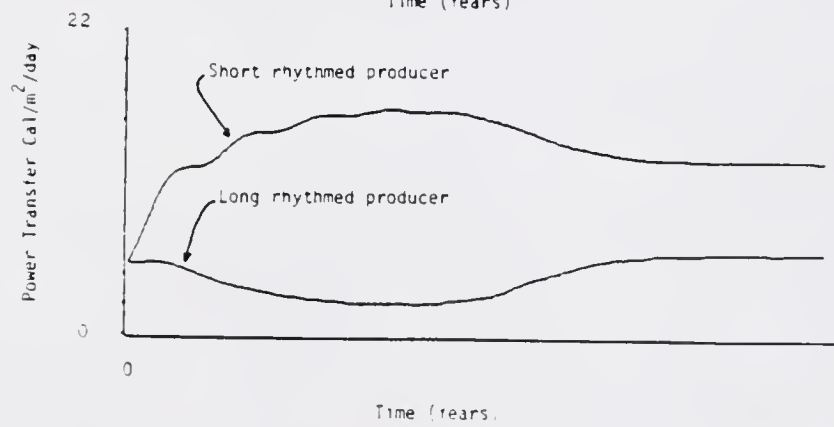
(b)



(c)



(d)



in question. The simulation plots shown in Figure 45 clearly indicate the advantage of longer period feedback in this simulation to be increased system diversity.

Kaituna Salt Marsh Mini-model with Competition Between an Energy-Selective Producer and a Non-energy Selective Producer

The intent of this simulation was to analyze the competitive strength of an energy-selective producer when competing with a non-energy-selective producer. The system period relationships are shown in Figure 60a. The energy-acceptance niche of the energy-selective producer is shown in Figure 60b. The niche for the non-energy-selective producer is not shown because it accepts energy at all frequencies or periods.

Figure 61 is an energy circuit diagram of the Kaituna marsh model with the addition of a non-energy-selective competitor. Figures 62a through 62d present the simulation results. The biomass plots for the two producers clearly indicate the competitive advantage offered by energy-selective behavior. The energy-selective Spartina unit competitively excludes the non-energy-selective unit rapidly and with little or no difficulty. Biomass for the energy-selective producer reaches a maximum level of 1100 g C m^{-2} while the biomass of the non-energy-selective producer decreases to a level of exclusion. Dead matter within the system reaches a level of 9500 g C m^{-2} as in many of the previous simulations, and the storage of nutrients reaches a level of 1000 g n m^{-2} . The producer unit and transfer power plots clearly indicate the dominance of the energy-selective Spartina producer. The plot of unit power for the two competitors indicates that the energy-selective producer quickly captures the available energy of the source,

Figure 60: The system relative niche and period relationships for the modified Kaituna marsh model including one energy-selective and one non-energy-selective producer. The system has a annual and diurnal source rhythm and one producer has a diurnal internal rhythmic pattern. The system is energy-selective and one producer senses or times the environmental energy source. The energy-selective producer is the better competitor. Diagram (a) shows the relative system periods (b) shows the relative energy-acceptance niches. The non-energy-selective producer acquires energy at all periods but not as effectively as the energy-selective producer in the range or niche of the energy-selective unit.

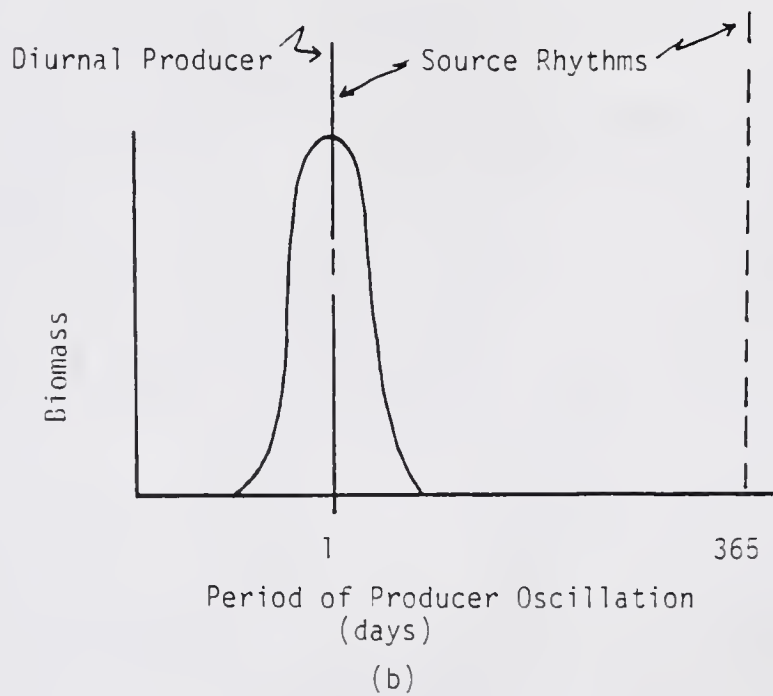
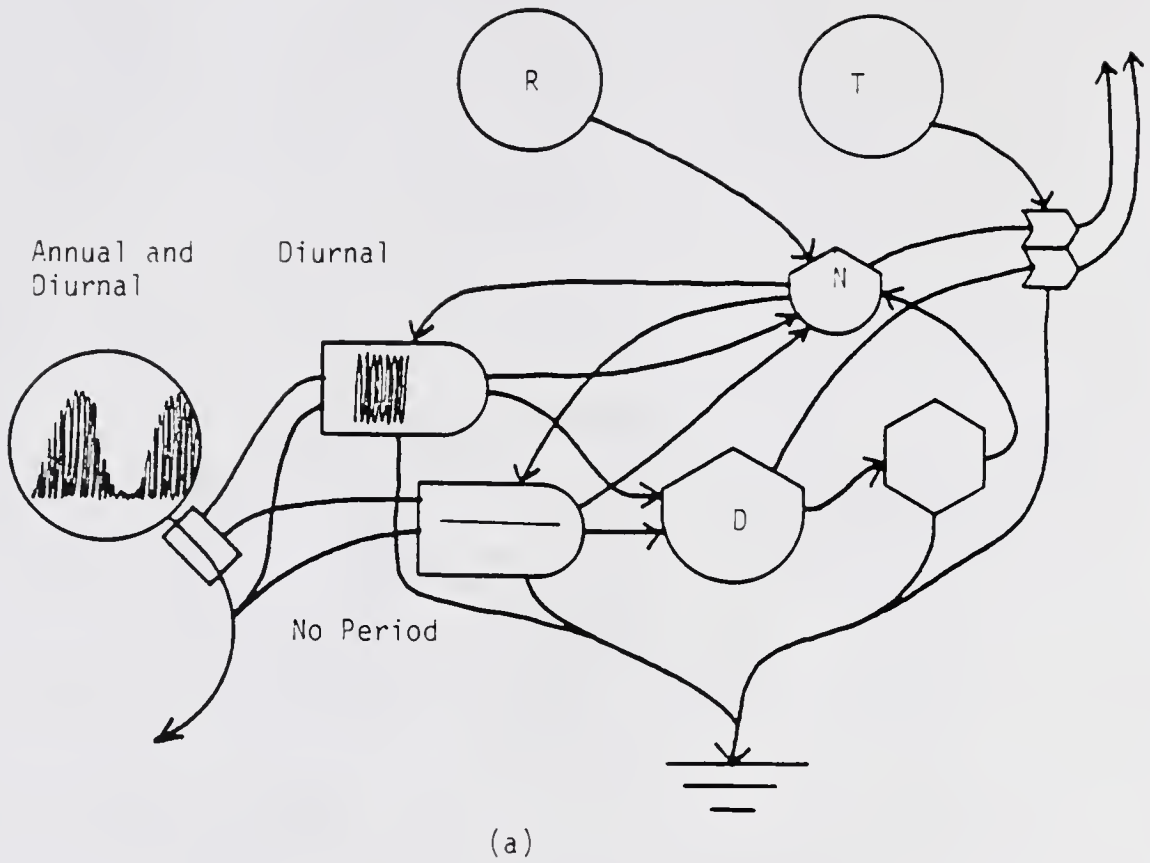


Figure 61: Energy circuit model for competition within the Kaituna marsh between an energy selective producer and a non-energy selective producer.

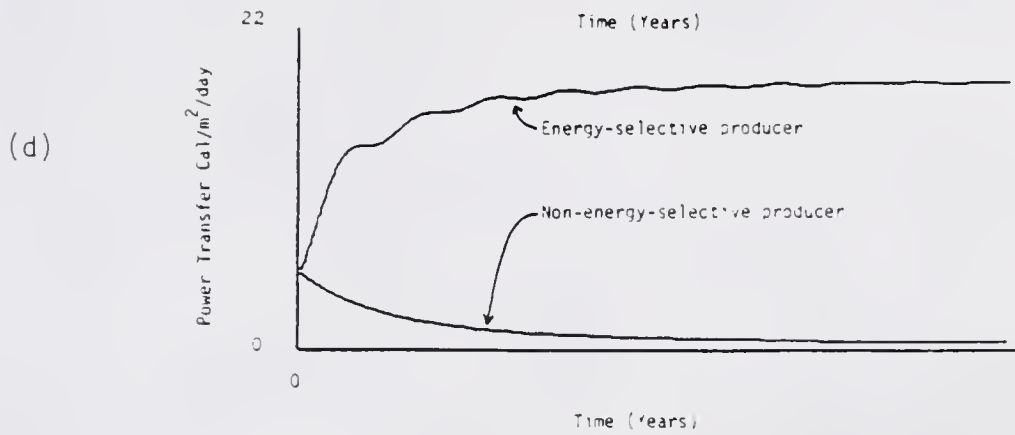
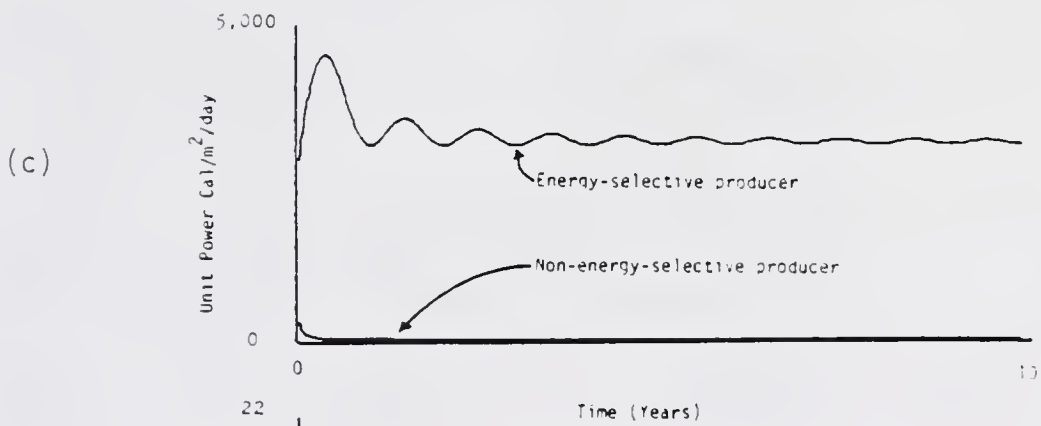
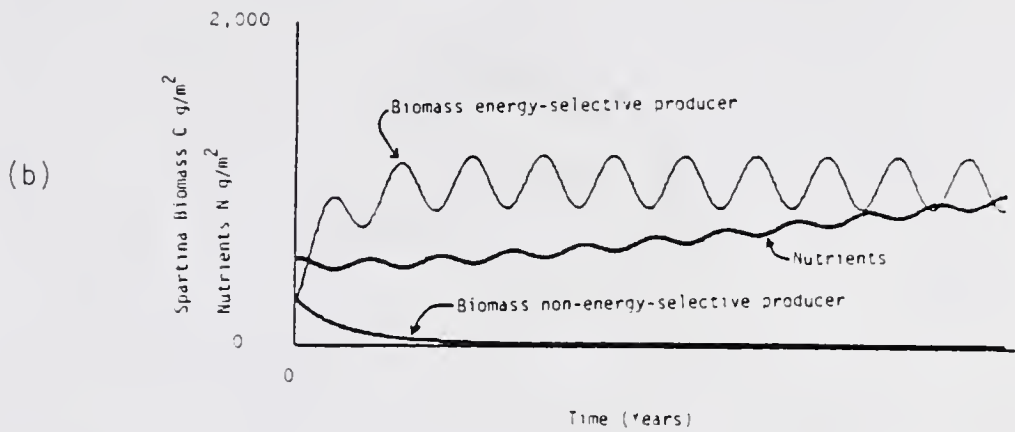
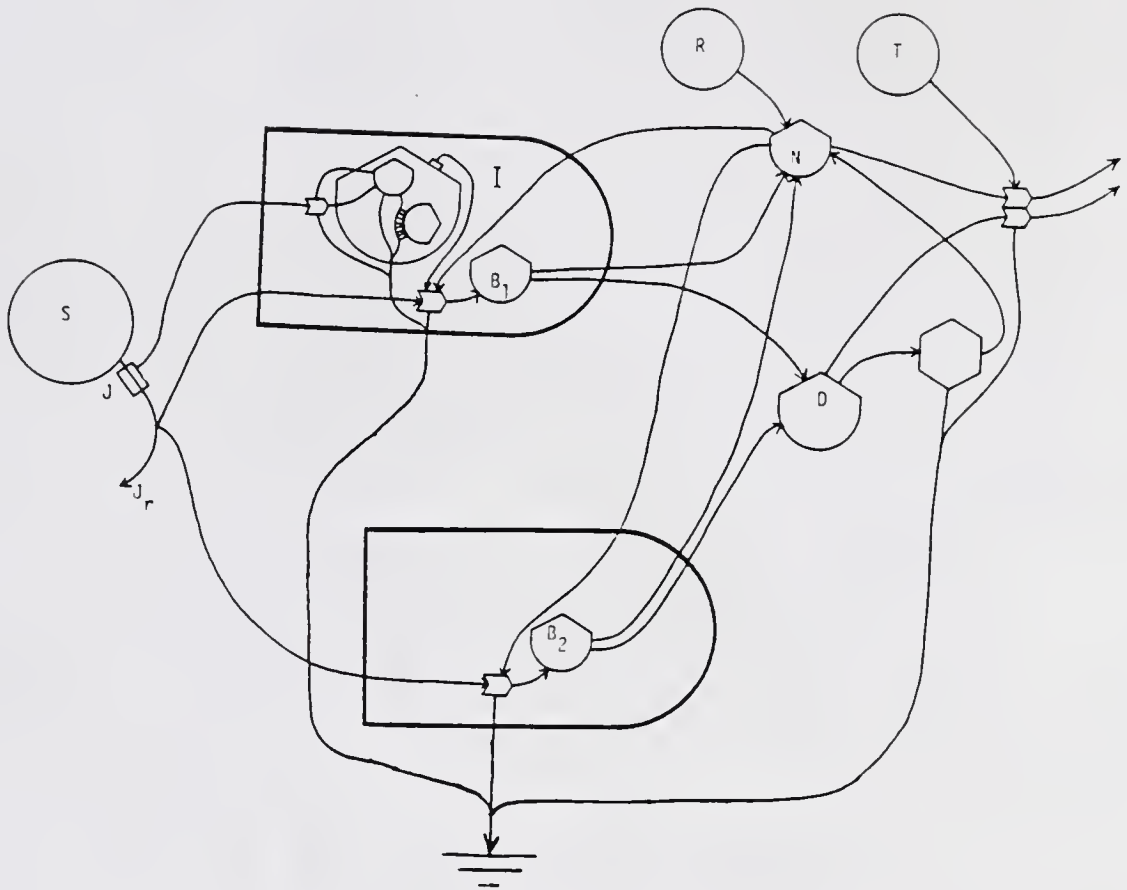


Figure 62: Plots for competition between an energy-selective producer and a non-energy-selective producer. Plot (a) sediment carbon. Plot (b) biomass and system nutrients. Plot (c) unit power. Plot (d) power transfer for the competitors. Clearly the energy selective producer prevails.



$$J_r = J / (1 + k_0 I N + k_{10} N)$$

$$dB_1/dt = k_1 J_r I N - k_2 B_1 - k_3 B_1$$

$$dD/dt = k_2 B_1 + k_{12} B_2 - k_4 D - k_5 D T$$

$$dB_2/dt = k_{11} J_r N - k_{12} B_2 - k_{13} B_2$$

$$dN/dt = k_3 B_1 + k_4 k_6 D + k_8 R + k_{13} B_2 - k_7 N T - k_9 J_r I N - k_{19} J_r N$$

Table 8: Evaluation, Name, Description, and Equations for the Energy Flows and Storages for Competition Between Energy Selective and Non-energy Selective Modules in the Kaituna Marsh

Component/Storage/Flow	Value	Name or Description	Equation
Sun	3450	$\text{Cal/m}^2/\text{d}$ Solar energy	$3450 + 2250 \cdot \sin(\omega_y \cdot t) \cdot S$
S	-	-	$\sin(\omega_d \cdot t)$ if $qt \neq 0$ else 0
B ₁	261.5	Biomass unit #1	$k_1 \cdot J_r \cdot I_1 \cdot N - k_2 \cdot B_1 - k_3 \cdot B_1$
B ₂	261.5	Biomass unit #2	$k_{11} \cdot J_r \cdot N - k_{12} \cdot B_2 - k_{13} \cdot B_2$
D	5226	Dead matter	$k_2 \cdot B_1 + k_{12} \cdot B_2 - k_4 \cdot D - k_5 \cdot D \cdot I$
N	523	Nutrients	$k_3 \cdot B_1 + k_{13} \cdot B_2 + k_4 \cdot D + k_6 \cdot D \cdot k_8 \cdot R - k_7 \cdot I - k_9 \cdot J_r \cdot I_1 \cdot N - k_{19} \cdot J_r$
R	4.26E+5	River input	$4.26E + 5 + 2.13E + 5 \cdot \cos(\omega_y \cdot t)$
I	1.13E+6	Tide energy	$1.13E + 6 + 5.65E + 5 \cdot \sin(\omega_I \cdot t)$
F ₀	1380	$\text{Cal/m}^2/\text{d}$ Solar input to producer	$k_0 \cdot J_r \cdot I_1 \cdot N$
f ₁	2.0	Biomass production #1	$k_1 \cdot J_r \cdot I_1 \cdot N$
f ₂	1.05	Biomass to dead matter	$k_2 \cdot J_r \cdot I_1 \cdot N$
f ₃	0.105	Biomass to nutrients	$k_3 \cdot B_1$
f ₄	1.59	Dead matter to consumer	$k_4 \cdot D$
f ₅	0.48	Dead matter export	$k_5 \cdot D \cdot I$
f ₆	0.29	Conversion dead matter to nutrients	$k_6 \cdot k_4 \cdot D$
f ₇	0.09	Nutrient export	$k_7 \cdot N \cdot I$

Note: Table for Figure 62.

Table 8. (cont.)

Component/Storage/Flow	Value	Name or Description	Equation
f_8	0.39	N g/m^2 Nutrient import	k_8^{*R}
f_9	0.365	N g/m^2 Nutrient uptake #1	$k_9^{*J} r^{*I} {}^{*N}$
f_{10}		Same as f_0	$k_{10}^{*J} r^{*N}$
f_{11}		Same as f_1	$k_{11}^{*J} r^{*N}$
f_{12}		Same as f_2	k_{12}^{*B2}
f_{13}		Same as f_3	k_{13}^{*B2}
f_{19}		Same as f_9	$k_{19}^{*J} r^{*N}$

and as a result obtains the most source power--capturing a maximum of $4500 \text{ Cal m}^{-2} \text{ day}^{-1}$. The producer incapable of rhythmic behavior captures virtually no input power and is excluded within the first month of the competition. The plot of power transfer for the producers indicates that the energy selective producer transfers the most power to the remainder of the marsh food chain, reaching a level of $18 \text{ Cal m}^{-2} \text{ day}^{-1}$.

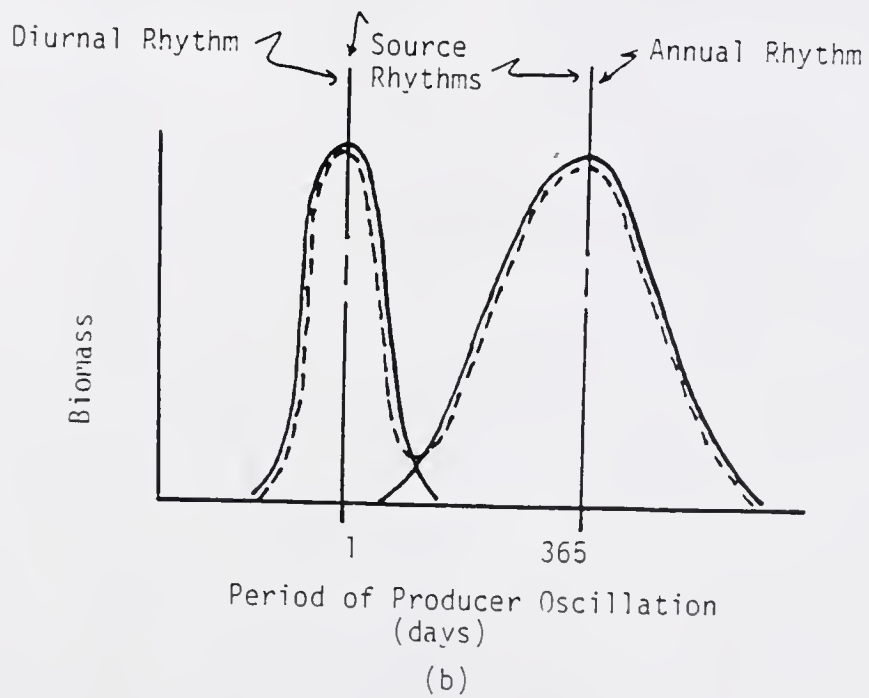
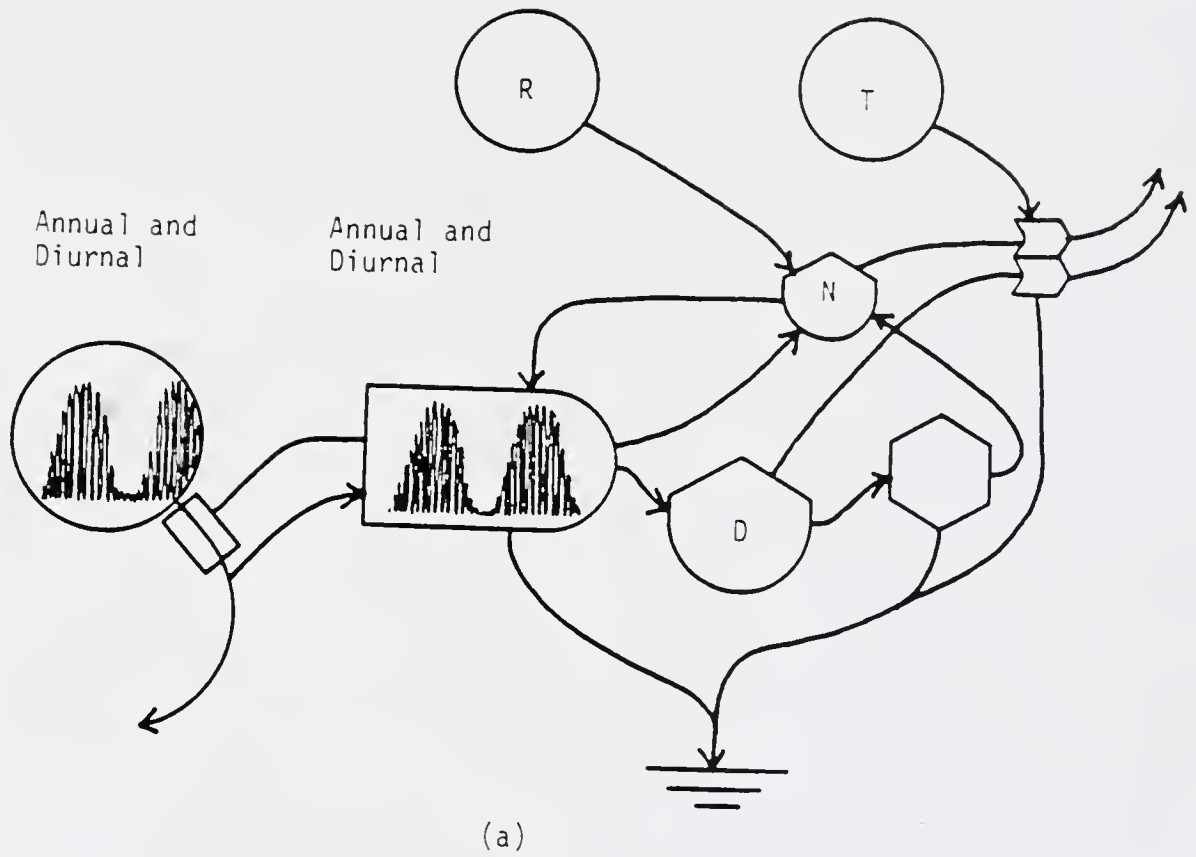
Table 8 summarizes the system initial conditions, pathway coefficients, and pathway coefficient equations for the simulation. The table provides a description of the flow or storage, and the equations for the model.

Kaituna Salt Marsh Mini-model with a Two-Oscillator Producer Competing for a Limited Energy Flow Composed of the Addition of Two Rhythms

The intent of this section is to show the effects on the Kaituna web from the addition of an Spartina producer with two inertial oscillators. Figure 63a and 63b show the system period relationships and energy-acceptance niche for the producer.

Figures 65a through 65d show the results of the Kaituna mini-model simulation which contains the complex energy-selective producer in Figure 64. The producer uses an internal behavior composed of and guided by the interaction of two biological inertial oscillators. The first autocatalytic inertial oscillator produces a circadian rhythmic behavioral pattern, while the second autocatalytic inertial oscillator produces a circannual rhythmic behavior. The combination of the two inertial oscillators provides the producer with a behavioral pattern sensitive to both of the rhythms of the source. The result, as indicated from the plots in the figures, provide some interesting facts.

Figure 63: The system relative niche and period relationships for the modified Kaituna marsh model including one energy-selective producer. The system has a annual and diurnal source rhythm and one producer with a diurnal and annual internal rhythmic pattern. The system is energy-selective and the producer senses or times the environmental energy source. The energy-selective producer generates a niche with two areas of energy-acceptance. Diagram (a) shows the relative system periods (b) shows the relative energy-acceptance niches. The energy-selective producer acquires energy at all periods.

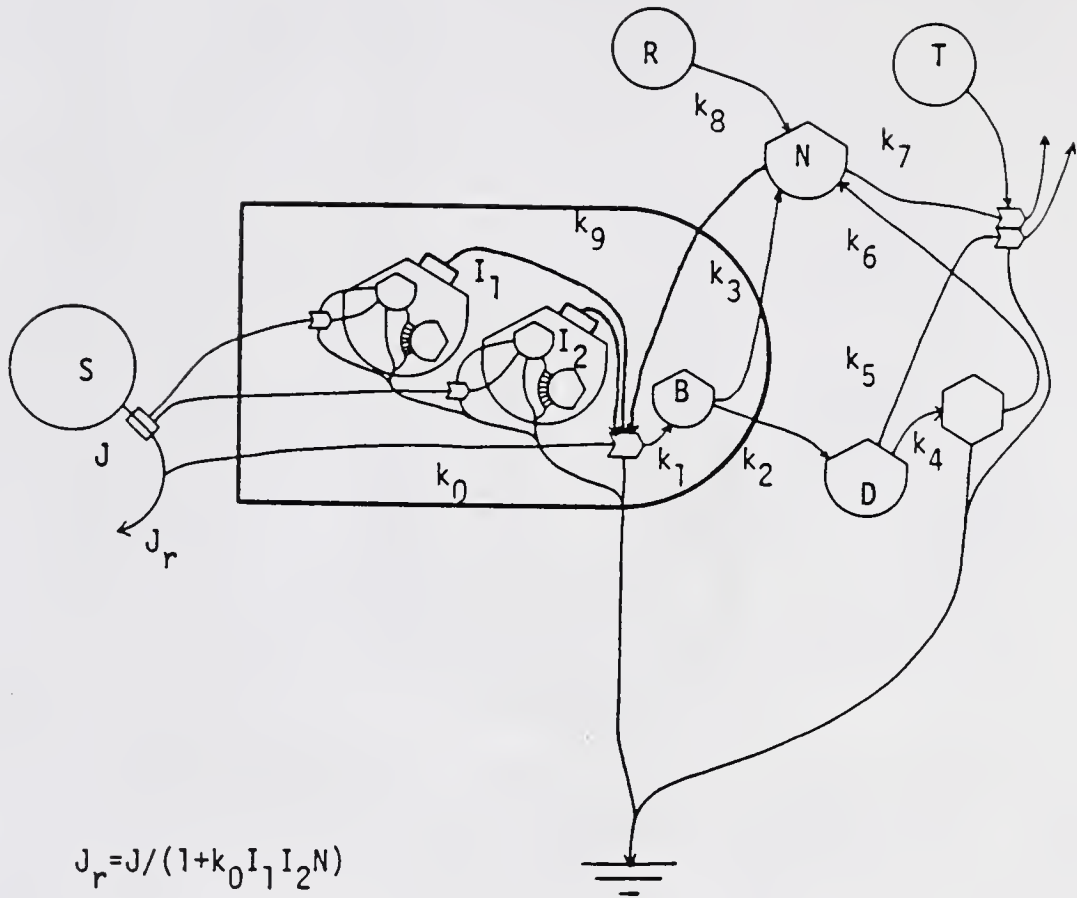


The addition of the second oscillator does not significantly effect the generation of producer biomass, only slightly increasing it to 1200 g C⁻² m. The system receives no more input solar power from the two oscillator producer than it did from the same producer guided by a single internal biological oscillator.

Spartina unit power, Figure 65c, is the same for the complex producer as it was for the single inertial oscillator producer; and the power transfer by the two inertial oscillator producer to the remainder of the system, Figure 65d, is the same as for the single inertial oscillator or simple Spartina producer. That does not however indicate that the producer is wasting time and presumably energy in developing itself as a more complex unit. The fact is the unit is a generalist. With the development or addition of the new inertial oscillator the unit adds a new dimension to its energy selective behavior, and benefits from the new behavioral additions when placed into a competitive environment. The results of the simulation indicate only that the addition of more complex behavior does not hinder the producer's normal performance. However, the two complex Spartina producer does reach steady state conditions more rapidly, and this aspect should aid in competition with other producers.

Tables 9 presents the initial condition for the model storages, flow coefficients, and pathway equations. No pathway flows were changed during the simulation of this model. The only addition to the model is a second autocatalytic inertial oscillator within the Spartina production module.

Figure 64: Energy diagram of a two-clock producer positioned in the Kaituna marsh web.



$$J_r = J / (1 + k_0 I_1 I_2 N)$$

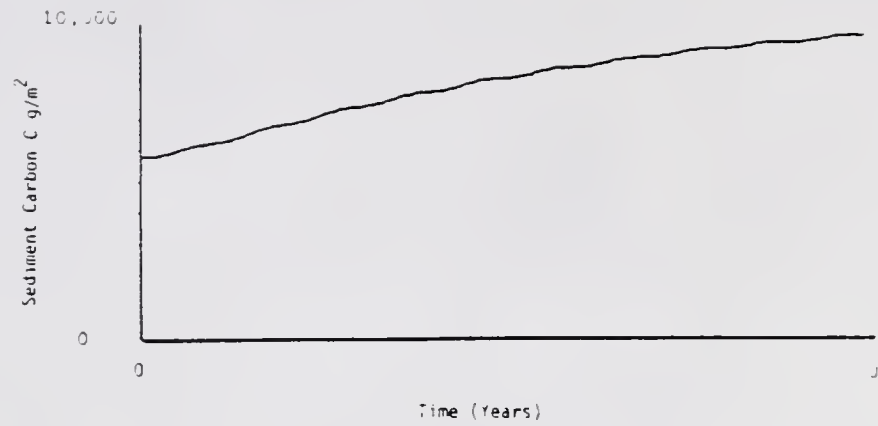
$$dB/dt = k_1 I_1 I_2 J_r N - k_2 B - k_3 B$$

$$dD/dt = k_2 B - k_4 D - k_5 DT$$

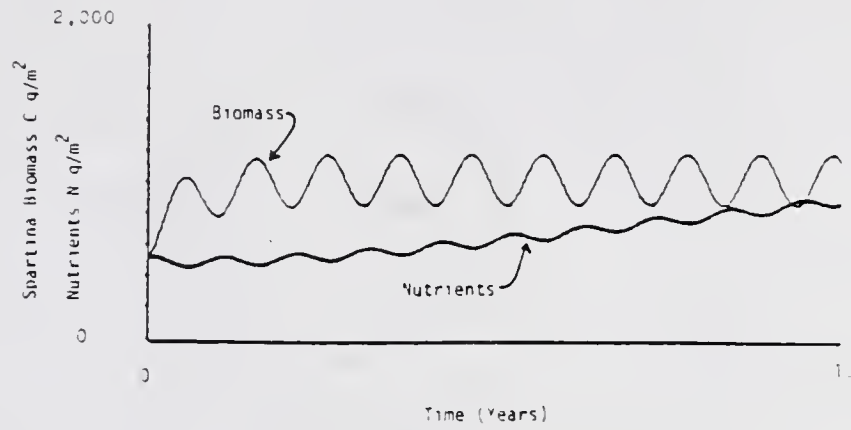
$$dN/dt = k_3 B + k_4 k_6 D + k_8 R - k_7 NT - k_9 J_r I_1 I_2 N$$

Figure 65: Plots for the two-clock Spartina producer located in the Kaituna marsh. Plot (a) sediment carbon. Plot (b) biomass and system nutrients. Plot (c) Spartina unit power. Plot (d) Spartina power transfer. The simulation plots indicate that the addition of a second clock produces no change in system state variables. This finding coincides with the earlier competition models in the previous section. However, earlier models indicate that the producer is a more competitive unit than is a

(a)



(b)



(c)



(d)

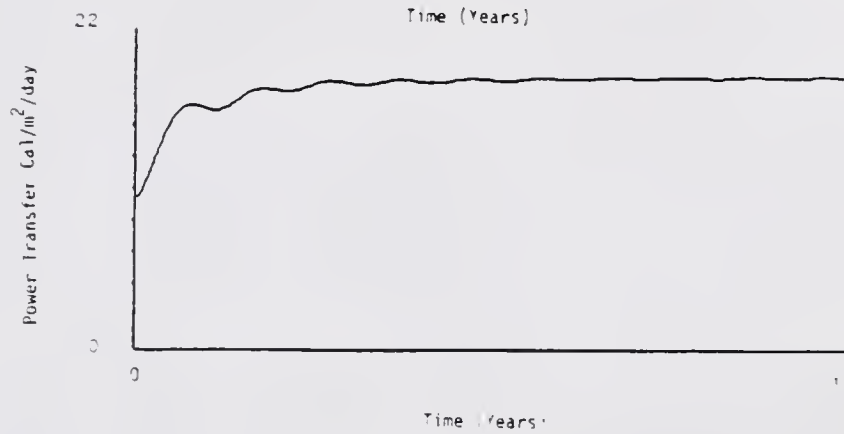


Table 9: Evaluation, Name, Description, and Equations for the Energy Flows and Storages in the Kaituna Marsh Model with a Two Clock Complex Producer

Component/Storage/Flow	Value	Name or Description	Equation
Sun	3450	Solar energy	$3450 + 2250^{\omega} \sin(\omega_y^{\omega} t)^{\omega} S$
B	523	Biomass	$k_1^{\omega} J r^{\omega} C l o c k_1^{\omega} l_2^{\omega} N - k_2^{\omega} B - k_3^{\omega} B$
D	5226	Dead matter	$k_2^{\omega} B - k_4^{\omega} D - k_5^{\omega} D^{\omega} T$
N	523	Nutrients	$k_3^{\omega} B + k_6^{\omega} k_4^{\omega} D + k_8^{\omega} R - k_7^{\omega} T$
F ₀	2760	Solar input to producer	$k_0^{\omega} J r^{\omega} N^{\omega} l_1^{\omega} l_2$
F ₁	4.0	Biomass production	$k_1^{\omega} J r^{\omega} N^{\omega} l_1^{\omega} l_2$
F ₂	2.1	Biomass to dead matter	$k_2^{\omega} B$
F ₃	0.21	Biomass to nutrients	$k_3^{\omega} B$
F ₄	1.59	Dead matter to consumer	$k_4^{\omega} D$
F ₅	0.48	Dead matter export	$k_5^{\omega} D^{\omega} T$
F ₆	0.29	Conversion dead matter to nutrients	$k_4^{\omega} k_6^{\omega} D$
F ₇	0.09	Nutrient export	$k_7^{\omega} N^{\omega} T$
F ₈	0.39	Nutrient import	$k_8^{\omega} R$
F ₉	0.73	Nutrient uptake in biomass production	$k_9^{\omega} J r^{\omega} N^{\omega} l_1^{\omega} l_2$
R	4.26e+5	River input	$4.26E + 5.213E + 5^{\omega} \cos(\omega_y^{\omega} t)$
T	1.13E+6	Tide energy	$1.13E + 6 + 5.65E + 5^{\omega} \sin(\omega_y^{\omega} t)$

Note: Table for Figure 64.

DISCUSSION

The following discussion is presented in three sections. First, the discussion concentrates on the autocatalytic inertial oscillator developed during this research. Next, the discussion continues with energy-selective behavior and its effects on niche, diversity, competition, and maximum power. The previous effects are presented with the discussion concerning maximum power interwoven throughout the sections devoted to niche, diversity, and competition. Third, future research topics are described, including the possibility that energy selectivity is a general systems principle, and what future research might be undertaken in order to prove or disprove that possibility. The possibility of the relevance of the autocatalytic inertial oscillator as a physiological clock is also discussed.

The Autocatalytic Inertial Oscillator

Autocatalytic inertial oscillators provide systems with a means of selecting energy and power inputs. The use of inertial oscillators by systems clearly produces an energy-selective activity for that system, and as a result, produces power transfer for a selected range of input energies.

In the previous section autocatalytic inertial oscillators were shown to aid in the development of a system energy-acceptance niche. The system's energy-acceptance niche being described or defined by the

range of input energies a system utilizes for the particular internal rhythmic pattern it possess or generates. This research has shown that an energy-acceptance niche for a system may be defined by the generation of an internal autocatalytic inertial oscillation. When the period or frequency of the available energy is too far removed from that of the system's internal autocatalytic inertial oscillation then energy is rejected and the system must utilize other sources if it is to survive.

Simulations in the previous section also indicate that the autocatalytic inertial oscillator plays a role in defining the competitive advantage one system has over another system. The system that most closely duplicates the period of the available source energy survives in competition with other single rhythmmed systems. Furthermore, energy-selective behavior is advantageous even when competing with a non-energy-selective system. If the available energy supply is rhythmic and within the acceptance range of an energy-selective system that system effectively outcompetes a non-energy-selective system. Competition between a single rhythmmed system and a more complex generalist system leads to the competitive exclusion of the single rhythmmed system.

Simulations have also indicated that competition for available energy can produce coexistence of competing energy-selective systems. The overlapping of energy-acceptance niches generated by internal autocatalytic inertial oscillators can produce both competitive exclusion and coexistence. When the rhythms generated by the competing systems' autocatalytic inertial oscillators match closely by period and are closely matched with their common energy source the result is competitive coexistence. When the internal autocatalytic inertial

oscillations of the competitors differ greatly then the result of competition is competitive exclusion.

External and Internal Timing of System Oscillations

The problem of external or internal timing is important to the concept of energy-selectivity. If timing is generated externally then the generation of energy-selective behavior is not likely to occur! Without an autonomous internal rhythm to guide the rhythmic activity of a system the system merely reflects the rhythm of its environment. The ability to be energy-selective, that is to reject energy because it is not of the same or closely related period, depends upon the ability to discern a different period of fluctuation. Without the ability to generate an internal free-running rhythmic activity a system can only reflect the rhythm of its environment and therefore cannot discern any difference between its rhythmic activity and that of the environment.

Energy Selectivity and Systems

Simulation plots in the results section of this analysis indicate that systems which have the ability to generate internal rhythmic patterns compete for energy within a given range (energy-acceptance niche) of energy alternatives, and do so more effectively than units that cannot act to selectively choose their energy input. Furthermore, the range of the system's internal rhythmic behavior cannot vary too far from the frequency of its primary energy source. If a system generates a rhythmic internal guide that is too far removed from that of its energy source the system will not survive. Within a system's energy-acceptance niche survival is determined by the strength of its competitiveness. Factors effecting the competitive strength of a systems include the

strength and quality of the feedback available to the system from other systems and components, the closeness of the system's internal rhythm to that of the rhythm of its primary energy source, the system's power transfer capabilities, i.e. its participation in the larger system's maximization of power, and the competitive strength of the systems with which it must compete.

The simulations presented in this study indicate that energy input is most efficiently accomplished when the system's internal autocatalytic inertial rhythmic activity is at the same period as its primary energy source. Therefore, the greatest power input and power transfer is accomplished at free-running internal rhythm of the system when that rhythm is of the same period as that of the system's primary source energy. All source energy with periods outside of the system's energy-acceptance niche are rejected and no power is transferred by the system. For source energy within the system's energy acceptance niche but not at the same frequency or period as the system's free-running oscillation energy and power are accepted but not at the most efficient rate. Thus power transfer may occur in energy-selective systems at other than the maximum power transfer capabilities of the system.

Transfer of power at other than the most efficient rates may reflect the necessity for increased diversity. A larger number of components transferring power at lesser rates may still be able to transfer the same amount of power to the next larger system as that of a single highly efficient specialist.

Energy Selectivity and the Autonomous Inertial Oscillations

The advantages for an autonomous inertial oscillator can be argued from the point that it may provide a more diverse and health system.

The ability of an individual system to develop its own autocatalytic internal rhythmic guide as a result of its inertial components has been shown to be important to the system as well as to the individual. If all systems simply internalize external environmental signals then their would be less selectivity and less system diversity. The ability to generate an energy-selective activity aids in the creation of more diverse ecosystems because energy rejected by one component of the ecosystem is energy available for use by another component of an ecosystem. While diversity is generated without energy-selective behavior the addition of energy-selective behavior may aid in the production of greater diversity.

When individual systems produce different, yet close, internal autonomous rhythms the interaction of their internal rhythms with that of the environment's rhythms produces a greater variety of systems. As has been stated, the simple internalization of external variables cannot produce energy-selective behavior. Only the interaction of an internal autonomous oscillation operating within an environment subject to cyclic change can produce an energy-selective activity within its system. That is not to say that a system that internalizes an external signal could not time the environment but it would not have the ability to be energy-selective. Energy selective behavior requires the system to produce its own autonomous oscillation! The oscillations studied for this research were inertially generated but the principle may be expanded to include other internally generated oscillations.

Energy Selectivity and the System

What does the system obtain by selecting for system components which exhibit energy-selective behavior? This question is best answered by the "principle of maximum power".

The principle of maximum power is stated as follows. Systems which obtain the most available energy, use that energy most efficiently, and provide the next higher system with a means of maximizing its power ultimately survive. Energy selective behavior by individual subsystems result in the maximization of system power because energy selectivity produces greater diversity. When individuals have the capability of selecting their energy input the reciprocal also holds, they must as a consequence of their selection of some energies reject other energies. The rejection of energy by one system component results in the availability of that energy for use by another system component. Therefore, energy rejection by one system component releases energy for use by another component and produces greater system diversity. Increased diversity leads to greater specialization of system components, and energy specialization through the use of energy selectivity results in a more efficient utilization of the available energy input producing greater power transfer to system components higher in the system web or chain.

The simulation plots in the results section indicate that energy-selective specialization requires that a system's energy-acceptance niche be closer to its primary energy frequency than if the component is a generalist. Power transfer is for the most part more efficiently accomplished by a specialist than it is for a generalist. The exception occurs when a generalist's internal rhythm is closely matched to its

primary energy frequency and its selectivity range includes one or more secondary energy frequencies. Therefore, energy-selective activity within an ecosystem results in more diversity, more efficient use of available energy, and more energy and power transmitted to components higher in the system web or chain.

Energy Selectivity and the Energy Acceptance Niche

The development of an energy-selective behavior contributes directly to the establishment of a system niche. When the free-running period of the system's internal rhythm is equal to and phased with an environmental cycle the system obtains the greatest amount of energy from the environment and as a consequence generates the greatest amount of biomass. If the free-running rhythm of a system is not equal to and phased with its primary environmental cycle the energy it accepts is decreased or entirely rejected and its biomass production decrease or halts. The interaction of an environmental rhythm with that of the system's internal autonomous rhythm produces selective energy acquisition within the system's energy-acceptance niche.

When a system component fills a niche it occupies a space in the web of the environment. The filling of a energy-acceptance niche signifies that the component occupying that niche for both internal and external reasons passes the system's requirement for that space and function.

When a system possesses the ability to selectively accept or reject energy it defines a range of inputs it will compete to obtain. The simple generalist will try to obtain energy from a wider range of inputs than will a specialist, and when no other system or component offers competition a simple generalist will accept energies from a fairly wide

range of alternatives. However, a specialist is more successful in competition within its defined range than is a simple generalist.

The complex generalist, on the other hand, is an extremely competitive system component and can compete effectively because it has developed the ability to time its environment and accept energies from a variety of external cycles. The ability to time a multitude of external rhythms provides the complex generalist with a competitive advantage when faced with another competing system or component. Simulations have shown that even systems with the ability to narrow their acceptance range to the extreme fail in their attempt to outcompete a complex generalist if that generalist possesses the ability to time the primary rhythm of the specialist. The complex generalist understands more about its environment than other systems, however it can outcompete a specialist only if it has the ability to time the specialist's fundamental rhythm. A specialist and a complex generalists coexist only if the complex generalist does not possess the ability to time the specialist's fundamental rhythm. The coexistence of systems, at least from an energy-selective perspective, occurs from an ability to selectively obtain different environmental energies or the same energy at periods close to both competitors fundamental rhythms.

Energy Selectivity and Diversity

When energy input is available the ecosystem finds a way to utilize that energy! This is a partial restatement of the principle of maximum power. The utilization of available energies would occur even if energy-selective behavior did not exist. However, for the same input energy available, energy selective behavior results in a more efficient and specific use of energy by the components of a system. Energy

selective system components acquire input energy within a range of alternatives. Therefore selective behavior allocates energy among system components and among systems, and as a result of their selection of energy about specific primary frequencies.

When available input energy is present at a number of frequencies energy-selective system components acquire only the energies available within their energy-acceptance niches, the remainder of frequencies are rejected. The rejected energies are then available for use by other energy-selective system components. This type of energy allocation (between a variety of energy-selective components) increases the overall diversity of the system.

The complication of energy distribution because of selective behavior is indicated by examining a theoretical system with only one energy input consisting of two primary frequencies. When specialists are available to accept energy at both frequencies then the input energy will be divided by the two specialists. When the internal characteristics of the two specialists are the same and only their internal rhythms differ then more energy is acquired by the specialist with the nearest rhythmic match to that of its specific source energy rhythm. When both units match exactly to their primary energy rhythm then the system component with the faster internal rhythm acquires more energy, but both units survive.

When two specialist with different internal characteristics are available to accept energy from the source--competitive exclusion may result, if and only if, both primary rhythms of the source are also within one specialist's energy acceptance niche. When energies from the two primary rhythms of the source are allocated between the specialists,

one to each specialist and with no range overlap for the units, then no competition occurs and the two specialists coexist on the same energy source. Moreover, each unit receives energy from one of the two separate rhythmic components of the same source energy. Energy-selective behavior allows system components to exist on different energy frequencies from the same source. The concept might be thought of as a means of allocating energy from the same quality source among groups of different systems. In other words, competition need not occur to allocate different periodic energies from the same energy quality source.

Future Investigation

This study has addressed the concept of energy selectivity from an internal autocatalytic inertial oscillator's generation of intrinsic rhythmic behavior within systems. The ability of systems to act with an inertial backpressure from an internal oscillation may be one method by which energy-selective designs are accomplished for general ecosystem use. However, some important questions still remain for future investigation. Is it possible that the biological clock is composed of a potential and kinetic components, and if so do these components vary widely in use and design? Furthermore, do systems have other ways to utilizing potential and kinetic components as time keeping mechanisms?

The Autocatalytic Inertial Oscillator and Design Characteristics

Simple electrical and mechanical oscillators are constructed of potential and kinetic components that have identifiable properties which allow an engineer to choose which component best fits a particular situation. Ecosystem oscillators are more complex and the ecologist or

biologist working with the concept of energy-selective ecosystem components is left in the dark with no idea of what the ecosystem's potential or kinetic component design values are. While it appears to be relatively easy to determine the free-running period for a particular system, given that the system rhythm generator does not have a high depreciation, no data are available to determine what value should be given to the potential or kinetic ecosystem components which may be responsible for the rhythm. Therefore, research needs to be conducted that would allow the determination of specific values for ecosystem inertial or rhythm generating components! If an analyst knew that a particular component acted as a potential generator for a specific system's rhythmic behavior, and also observed the free-running rhythm of the system it might provide some clues as to the nature of an unknown kinetic component. New research should be directed toward identifying a method that could determine the potential and kinetic properties of components for individual system or ecosystem inertial rhythms. Once standard values for inertial or rhythmic components are identified analysis of rhythmic activity might be more easily accomplished.

Energy Selectivity

Energy-selective behavior in general ecosystem designs have been clearly indicated by the plots and figures presented for this study. Much work has already been completed but more work remains. The ability of energy-selective system to define an energy-acceptance niche has been shown quite convincingly, however more work must be completed to identify how much of an effect energy selectivity has on the other aspects of niche development.

The Effects of Energy Selectivity Within Autocatalytic Systems

The addition of autocatalytic behavior within energy circuit models clearly indicates the advantage of internal feedback in ecosystem design (Odum 1976 and 1983). If that system also utilized autocatalytic feedback as a pumping action within its defined energy-acceptance range it should be an even more competitive system component. Therefore, research should be conducted into the effects of energy-selective activity for autocatalytic ecosystem components.

Energy Selectivity and Competitive Strength in Constant Conditions

Experiments to determine the competitiveness of systems in constant conditions might provide insight into the competitive strength of the system, and could be used to establish ratios for energy-selective behavior by type of system. One might expect that systems would compete equally as well in constant conditions but that might not be the case. If a system relied heavily on its rhythmic internal guide and evolved a highly efficient energy-selective behavior it might not fair well in a competitive situation with another energy-selective or non-energy-selective system when both were placed into constant conditions. The likelihood exists that energy-selective behavior is stronger than non-energy-selective behavior only when the system is dependent upon a source of cyclic energy. The unit with a strong energy-selective behavior might be expected to compete poorly in constant conditions. Therefore, an energy selectivity index based on competitive strength in constant conditions might be employed to define a selectivity index, or to determine if the system possess any energy-selective behavior.

Energy Selectivity and the Effects of High Quality Pulsing Feedback

The effects of high quality pulsed feedback for non-selective systems is well defined. Alexander indicated that pulsed feedback increases the power of a system because the recycle-to-rebuild process uses more energy and power. Therefore, pulsed feedback in energy-selective systems would be expected to increase the power of the system, however this remains for future research.

Possible Relevance of Autocatalytic Oscillators to Physiological Clocks within Organisms

Physiological clocks have been studied for approximately 2000 years with the earliest identification of a biological rhythm occurring 2400 years ago. Before the birth of Aristotle, an amateur naturalist observed that legumes had a rhythmic pattern to their leaf movements (Brown, Hastings, and Palmer, 1970). By the beginning of the twentieth century, studies of rhythms in plants and animals had brought about a realization that these internal rhythms were the result of complex processes within the biological unit. Today the operation of biological clocks is still a mystery and internal rhythms have been identified in plants, terrestrial and marine organisms, amphibians, insects, and man (Brown, 1960; Brown, Bennett, and Webb, 1954; Bennett and Stanely, 1960; Alder, 1970; Goss, Dinsmore, Grimes, and Rosen, 1974). The major points of controversy about the internal operation of biological clocks include: a) whether the clock is internally or externally timed and b) whether the clock is temperature compensated.

Internal vs external timing relates to the ability of the clock to self-generate a free-running biological rhythm or whether the clock merely reflects the signals of its environment. The simulation models

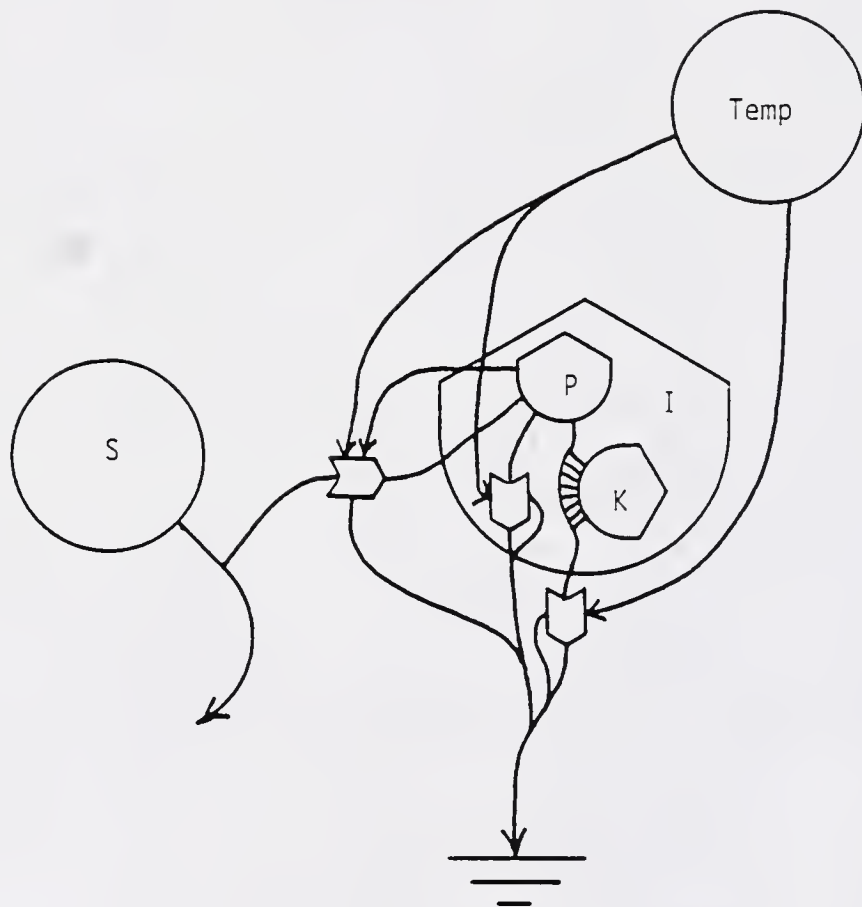
Figure 66: Energy diagram of a temperature compensated autocatalytic Inertial oscillator. The clock appears to be capable of explaining the observed temperature compensation by clocks.

completed for this study indicate that an internal oscillation with a free-running rhythm is necessary for the generation of energy-selective system behavior. If biological clocks were autocatalytic inertial oscillators internal timing would be advantageous for both the biological unit possessing the oscillator and for the system within which that component functions.

Temperature compensation of biological clocks has been proposed to explain the observed period stability of biological clocks for varying temperatures. The effects of temperature on the period of a biological clock is quite interesting. Research indicates that biological clocks are relatively insensitive to temperature changes in their environment, producing relatively stable periods for temperatures within a range of 5 °C to 30 °C (Bennett, 1974).

Three different hypotheses have been proposed to explain the accuracy of the biological clock with changing temperature (Palmer, 1976). First, the biological clock is constructed around a diffusion process and diffusion rates are less sensitive to temperature changes. Second, the chemical reactions of the clock are temperature compensated. Third, the biological clock is externally timed and therefore is only processing a rhythm and does not need to temperature compensate.

If biological rhythms were generated by an autocatalytic inertial oscillator temperature compensation could be accomplished by the interaction of the flows within the oscillator. The model in Figure b6 (although not simulated) would account for the effects of stable period development with changing temperature. The flows all change the same amount with increased or decreased temperature and as a result the oscillator period remains stable.



The advantages for energy-selective activity or behavior have clearly been demonstrated by the simulations of this research. The ability to act in an energy-selective manner has been shown to occur when a system, in a cyclic environment, develops an internal free-running rhythm. The energy-selective system selectively acquires input energy more efficiently and transfers more power with greater efficiency to the remainder of the system. The ability to acquire input energy more efficiently and to use that energy more efficiently, as stated by the principle of maximum power, provides the system with a greater competitive edge. Therefore, the development of biological oscillators or rhythm generators should be advantageous to the individual biological unit as well as the system it functions within.

APPENDIX

```
//BILFLOPE JUL (0.002,2002,95,2,0),PAUL.Z#ICK,CLASS=1
//STEP1 EXEC CSMP,
// CCMP=,
// EXCD=
```

```
INITIAL
```

```
INCCN IQ1=1.0
INCCN BIC1=100.0
INCCN XINU1=0.0
INCCN XINL1=0.0
PARAMETER URIN=100.0
PARAMETER JRIN=26.0
PARAMETER FREQ1=1.0
PARAMETER FREQS=0.10
PARAMETER ROIN=37.0
PARAMETER R1IN=3.0
PARAMETER R3IN=1.0
PARAMETER R10IN=37.0
PARAMETER R11IN=6.0
PARAMETER R12IN=3.0
PARAMETER R13IN=0.5
PARAMETER R14IN=0.5
PARAMETER C=1.0E-4
OMEGA1=2.0*3.1415973*FREQ1
OMEGAS=2.0*3.1415973*FREQS
L1=1/((OMEGA1**2)=C)
POT1=((IQ1**2)/(2*C))
KIN1=((L1/2)*(R14IN**2))
CLK1=POT1+KIN1
K0=ROIN/(CLK1*JRIN)
K1=R1IN/(CLK1*JRIN)
K3=R3IN/BIC1
K10=R10IN/(IQ1*JRIN)
K11=R11IN/(IQ1*JRIN)
K12=R12IN/(IQ1*JRIN)
K13=R13IN/IQ1
K14=OMEGA1**2
IS1=R14IN/K14
```

```
DYNAMIC
```

```
UF1=SCURCE/(1.0+K10*ABS(Q1))
UF=SCURCE/(1.0+K10*CLCK1)
SCURCE=100.0+50.0*SIN(OMEGAS*TIME)
XPRO1=UF1*ABS(Q1)
BPRO1=UF*CLCK1
FLOW0=X0*BPRO1
FLOW3=X3*BIC1*1
FLOW14=X14*S1
PU1=INTGRL(XINU1,FLOW0)
PL1=INTGRL(XINL1,FLOW3)
XKIN1=(L1/2)*(FLOW14**2)
XPOT1=Q1**2/(2*C)
CLCK1=XKIN1+XPOT1
DOCT1=(K11-K12)*XPRO1-K14*S1-K13*Q1
Q1=INTGRL(Q1,DOCT1)
S1=INTGRL(S1,Q1)
BOCT1=X1*BPRO1-K3*BIC1*1
BICM1=INTGRL(BIC1,BOCT1)
```

```
TERMINAL
```

```
TIMER =INTIM=700.0,DELMIN=2.0E-4S,DELT=2.0E-2,PROEL=1.0
METHOD SIMP
PRINT BICM1,PU1,PL1
```

```
END
STOP
ENCLOS
/*
```

```

//ELECT-IC JCB (2002,2002,29,2,0),PAUL.ZWICK,CLASS=2
//STEP1 EXEC CSMP,
// COMP=,
// LKED=
INITIAL
    INCON ICQ=0.0
    INCON ICS=0.0
    INCON ICXS=0.0
    INCON ICXL=0.0
    PARAMETER FREQ1=1.0
    PARAMETER FREQS=0.01
    PARAMETER RS=1000.0
    PARAMETER PL=1000.0
    PARAMETER C=1.0E-4
    OMEGA1=2.0*3.1415973*FREQ1
    OMEGA5=2.0*3.1415973*FREQS
    L=1/((OMEGA1**2)*C)
    X1=1/RS
    X2=OMEGA1**2
    X3=1/(PL*C)
DYNAMIC
    SOURCE=3.0*GIN(OMEGA5*TIME)
    XI1=X1*(SOURCE-Q/C)
    XI2=X2*S
    XI3=X3*Q
    XS=(XI1**2)*PS
    PS=INTGRL(ICXS,XS)
    XL=(XI3**2)*PL
    PL=INTGRL(ICXL,XL)
    XKIN=(L/2)*(XI2**2)
    XPOT=Q**2/(2*C)
    ENERGY=XKIN+XPOT
    QDOT=X1*(SOURCE-Q/C)-X2*S-X3*Q
    Q=INTGRL(ICQ,QDOT)
    S=INTGRL(ICS,Q)
TERMINAL
    TIMER FINTIM=35.0,DELMIN=2.0E-45,DELT=2.0E-2,PROEL=0.1
    METHOD SIMP
    PRINT SOURCE,Q,S,PS,PL,ENERGY
END
STOP
ENDJOB
/*

```

```
//BIOHOPE JOB (2002,2002,95,2,0),PAUL.ZWICK,CLASS=1
//STEP1 EXEC CSMP,
//          CCMP=,
//          LKCD=
INITIAL
```

```
INCON IQ1=1.0
INCON BIC1=100.0
INCON XINU1=0.0
INCON XINL1=0.0
PARAMETER JIN=100.0
PARAMETER JRIN=26.0
PARAMETER FREQ1=1.0
PARAMETER FREQS=0.10
PARAMETER ROIN=37.0
PARAMETER RIIN=3.0
PARAMETER R3IN=1.0
PARAMETER R10IN=37.0
PARAMETER R11IN=6.0
PARAMETER R12IN=3.0
PARAMETER R13IN=0.5
PARAMETER R14IN=0.5
PARAMETER C=1.0E-4
OMEGA1=2.0*3.1415973*FREQ1
OMEGA5=2.0*3.1415973*FREQS
L1=1/((OMEGA1**2)*C)
POT1=((IQ1**2)/(2*C))
KIN1=((L1/2)*(R14IN**2))
CLK1=POT1+KIN1
K0=ROIN/(CLK1*JRIN)
K1=RIIN/(CLK1*JRIN)
K3=R3IN/BIC1
K10=R10IN/(IQ1*JRIN)
K11=R11IN/(IQ1*JRIN)
K12=R12IN/(IQ1*JRIN)
K13=R13IN/IQ1
K14=OMEGA1**2
IS1=R14IN/K14
```

DYNAMIC

```
JF1=SOURCE/(1.0)+K10*ABS(Q1)
JF=SOURCE/(1.0)+K0*CLOCK1
SOURCE=100.0+50.0*SIN(OMEGA5*TIME)
XPRQ1=JR1*ABS(Q1)
BPPC1=JF*CLOCK1
FLOW0=K0*BPPC1
FLOW3=K3*BICM1
FLOW14=K14*S1
PU1=INTGRL(XINU1,FLOW0)
PL1=INTGRL(XINL1,FLOW3)
XKIN1=(L1/2)*(FLOW14**2)
XPOT1=Q1**2/(2*C)
CLOCK1=XKIN1+XPOT1
QDOT1=(K11-K12)*XPRC1-K14*S1-K13*Q1
Q1=INTGRL(IQ1,QDOT1)
S1=INTGRL(IS1,Q1)
BCUT1=K1*BPPC1-K3*BICM1
BICM1=INTGRL(BIC1,BCUT1)
```

TERMINAL

```
TIMER FINTIM=700.0,DELTMIN=2.0E-45,DELT=2.0E-2,PRODEL=1.0
METHOD SIMP
PRINT BICM1,PU1,PL1
```

```
END
STOP
ENDJOB
/*
```

```
//BIOCOMP JOB (2002,2002,16,2,0),PAUL.ZWICK,CLASS=2
//STEP1 EXEC CSMP,
//          CCMP=,
//          LKED=
INITIAL
```

```
INCON IQ1=1.0
INCON IQ2=1.0
INCON BIOQ1=100.0
INCON BIOQ2=100.0
INCON XINU1=0.0
INCON XINU2=0.0
INCON XINL1=0.0
INCON XINL2=0.0
PARAMETER JIN=100.0
PARAMETER JRIN=26.0
PARAMETER FREQ1=1.0
PARAMETER FREQ2=1.0
PARAMETER FREQS=1.0
PARAMETER ROIN=37.0
PARAMETER R1IN=3.0
PARAMETER R3IN=1.0
PARAMETER R5IN=37.0
PARAMETER R6IN=3.0
PARAMETER R8IN=1.0
PARAMETER R10IN=37.0
PARAMETER R11IN=6.0
PARAMETER R12IN=3.0
PARAMETER R13IN=0.5
PARAMETER R14IN=0.5
PARAMETER R15IN=37.0
PARAMETER R16IN=6.0
PARAMETER R17IN=3.0
PARAMETER R18IN=0.5
PARAMETER R19IN=0.5
PARAMETER C=1.0E-4
OMEGA1=2.0*3.1415973*FREQ1
OMEGA2=2.0*3.1415973*FREQ2
OMEGAS=2.0*3.1415973*FREQS
L1=1/((OMEGA1**2)*C)
L2=1/((OMEGA2**2)*C)
POT1=((IQ1**2)/(2*C))
POT2=((IQ2**2)/(2*C))
KIN1=((L1/2)*(R14IN**2))
KIN2=((L2/2)*(R19IN**2))
CLK1=POT1+KIN1
CLK2=POT2+KIN2
K0=ROIN/(CLK1*JRIN)
K1=R1IN/(CLK1*JRIN)
K3=R3IN/BIOQ1
K5=R5IN/(CLK2*JRIN)
K6=R6IN/(CLK2*JRIN)
K8=R8IN/BIOQ2
K10=R10IN/(IQ1*JRIN)
K11=R11IN/(IQ1*JRIN)
K12=R12IN/(IQ1*JRIN)
K13=R13IN/IQ1
K14=OMEGA1**2
K15=R15IN/(IQ2*JRIN)
K16=R16IN/(IQ2*JRIN)
K17=R17IN/(IQ2*JRIN)
K18=R18IN/IQ2
K19=OMEGA2**2
IS1=R14IN/K14
IS2=R19IN/K19
```

DYNAMIC

```

JR1=SOURCE/(1.0+K10*ABS(Q1))
JR2=SOURCE/(1.0+K15*ABS(Q2))
JR=SOURCE/(1.0+K0*CLOCK1+K5*CLOCK2)
SCURCE=100.0+50.0*SIN(OMEGAS*TIME)
XPRC1=JR1*ABS(Q1)
XPRC2=JR2*ABS(Q2)
BPRC1=JR*CLOCK1
BPRC2=JR*CLOCK2
FLCW0=K0*BPRC1
FLCW3=K3*BICM1
FLCW5=K5*BPRC2
FLCW8=K8*BICM2
FLCW14=K14*S1
FLCW19=K19*S2
PU1=INTGRL(XINU1,FLCW0)
PL1=INTGRL(XINL1,FLCW3)
XKIN1=(L1/2)*(FLCW14**2)
XPOT1=Q1**2/(2*C)
CLOCK1=XKIN1+XPOT1
PU2=INTGRL(XINU2,FLCW5)
PL2=INTGRL(XINL2,FLCW8)
XKIN2=(L2/2)*(FLCW19**2)
XPOT2=Q2**2/(2*C)
CLOCK2=XKIN2+XPOT2
QDOT1=(K11-K12)*XPRC1-K14*S1-K13*Q1
Q1=INTGRL(IQ1,QDOT1)
S1=INTGRL(IS1,Q1)
BDOT1=K1*BPRC1-K3*BICM1
SICM1=INTGRL(BIC1,BDOT1)
QDOT2=(K16-K17)*XPRC2-K19*S2-K18*Q2
Q2=INTGRL(IQ2,QDOT2)
S2=INTGRL(IS2,Q2)
BDOT2=K6*BPRC2-K8*BICM2
BICM2=INTGRL(BIC2,BDOT2)

```

TERMINAL

```

TIMER FINTIM=700.0,DELMIN=2.0E-45,DELT=2.0E-2,PROEL=1.0
METHOD SIMO
PRINT BICM1,BICM2,PU1,PL1,PU2,PL2

```

```

END
STOP
ENDJOB
/*

```

```
//MODEL1 JCB (2002,2002,150,2,0),PAUL.ZWICK,CLASS=1
//STEP1 EXEC CSMP,
//          COMP=,
//          LKED=
```

```
INITIAL
```

```
INCON IQ=10.0
INCON BIOC=1000.0
INCON NUTC=200.0
INCON IPU=0.0
INCON IPL=0.0
PARAMETER JC=3450.0
PARAMETER JRC=690.0
PARAMETER R0IN=2760.0
PARAMETER R1IN=4.0
PARAMETER R2IN=2.1
PARAMETER R3IN=0.73
PARAMETER R4IN=0.21
PARAMETER R5IN=2760.0
PARAMETER R7IN=5.69
PARAMETER R8IN=2.1
PARAMETER R9IN=0.21
PARAMETER R6IN=1.69
PARAMETER C=1.0E-4
FREQ=1.00
OMEGA=2*3.1415927*FREQ
L=1/(C*OMEGA**2)
CLOCKC=((IQ**2)/(2*C))+((L/2)*(R9IN**2))
X0=R0IN/(JRC*NUTC*CLOCKC)
X1=R1IN/(JRC*NUTC*CLOCKC)
X2=R2IN/BIOC
X3=R3IN/(JRC*NUTC*CLOCKC)
X4=R4IN/BIOC
X5=R5IN/(JRC*IQ)
X6=R6IN/(JRC*IQ)
X7=R7IN/(JRC*IQ)
X8=R8IN/IO
X9=OMEGA**2
SIC=R9IN/X23
TY=365
TD=1.0
CMEGAY=2.0*3.1415927/TY
CMEGAD=2.0*3.1415927/TD
```

```
DYNAMIC
NUSORT
```

```
SOLAR=SIN(CMEGAD*TIME)
IF (SOLAR.LT.0.0) SOLAR=0.0
JR=SUN/(1.0+X0*NUTC*CLOCKC)
SUN=(9759+6365*SIN(CMEGAY*TIME))*SOLAR
```

```
SORT
```

```
JR1=SUN/(1.0+X5*ABS(Q))
PU=INTGRL(IPU,F0)
F0=X0*CLOCKC*NUTC*JR
PL=INTGRL(IPL,LOAD)
LOAD=X2*BIO+X4*BIO
XPRO=JR1*ABS(Q)
QDOT=X7*XPRO-X6*XPRO-X9*S-X8*S
Q=INTGRL(IO,QDOT)
S=INTGRL(SIC,Q)
F9=X9*S
XPOT=(Q**2)/(2*C)
XKIN=(L/2)*F9**2
CLOCK=XPOT+XKIN
BDOT=X1*JR*NUTC*CLOCK-X2*BIO
BIO=INTGRL(BIOC,BDOT)
NDOT=X2*BIO-X3*JR*NUTC*CLOCK-X4*NUTC
NUT=INTGRL(NUTC,NDOT)
```

```
TERMINAL
```

```
TIME= FINTIM=3650.0,DELMIN=2.0E-45,DELT=0.01,PRODEL=10.0
MET=CD SIMP
PRINT BIO,NUT,PU,PL
```

```
END
STOP
ENDJOB
/*
```

```
//MARSH JOB (2002,2002,90,2,0),PAUL.ZWICK,CLASS=1
//STEP1 EXEC CSMP,
//          COMP=,
//          LKED=
INITIAL
```

```
INCON BIOC=523.0
INCON DEADC=5226.0
INCON NUTC=523.0
INCON PUI=0.0
INCON PLI=0.0
PARAMETER JC=3450.0
PARAMETER R0IN=2760.0
PARAMETER JRC=690.0
PARAMETER R1IN=4.0
PARAMETER R2IN=2.1
PARAMETER R3IN=0.21
PARAMETER R4IN=1.59
PARAMETER R5IN=0.48
PARAMETER R6IN=0.29
PARAMETER R7IN=0.09
PARAMETER R8IN=0.39
PARAMETER R9IN=0.73
PARAMETER RIV=6.39E5
PARAMETER TID=1.13E6
X0=R0IN/(JRC*NUTC)
X1=R1IN/(JRC*NUTC)
X2=R2IN/BIOC
X3=R3IN/BIOC
X4=R4IN/DEADC
X5=R5IN/(DEADC*TID)
X6=R6IN/R4IN
X7=R7IN/(NUTC*TID)
X8=R8IN/RIV
X9=R9IN/(JRC*NUTC)
OMEGAY=2.0*3.1415/365
OMEGAT=2.0*3.1415/14.77
```

DYNAMIC

```
RIVER=4.26E5+2.13E5*COS(OMEGAY*TIME)
TIDE=1.13E6+5.65E5*SIN(OMEGAT*TIME)
JR=SUN/(1.0+X0*NUT)
SUN=3450+2250*SIN(OMEGAY*TIME)
PU=INTGRL(PUI,FLWS)
PL=INTGRL(PLI,FLOWL)
FLWS=X0*JR*NUT
FLOWL=((X2*BIC)+(X3*BIC))
B0OT=X1*JR*NUT-X2*BIC-X3*BIC
BIC=INTGRL(BIOC,B0OT)
D0OT=X2*BIC-X4*DEAD-X5*DEAD*TIDE
DEAD=INTGRL(DEADC,D0OT)
NDOT=X8*RIVER+X3*BIC+X6*X4*DEAD-X7*NUT*TIDE-X9*NUT*JR
NUT=INTGRL(NUTC,NDOT)
```

TERMINAL

```
TIMER FINTIM=3650.0,DELMIN=2.0E-45,DELT=0.1,PROEL=10.0
METHOD SIMP
PRINT BIC,DEAD,NUT,PU,PL
```

```
END
STOP
ENDJOB
/*
```

```
//MARSH2 JOB (2002,2002,90,2,0),PAUL.ZWICK,CLASS=1
//STEP1 EXEC CSMP,
//          COMP=,
//          LKED=
```

```
INITIAL
```

```
INCON BIOC=523.0
INCON DEADC=5226.0
INCON NUTC=523.0
INCON PUI=0.0
INCON PLI=0.0
PARAMETER JC=3450.0
PARAMETER JRC=690.0
PARAMETER R0IN=2760.0
PARAMETER R1IN=4.0
PARAMETER R2IN=2.1
PARAMETER R3IN=0.21
PARAMETER R4IN=1.59
PARAMETER R5IN=0.48
PARAMETER R6IN=0.29
PARAMETER R7IN=0.09
PARAMETER R8IN=0.39
PARAMETER R9IN=0.73
PARAMETER RIV=6.39E5
PARAMETER TID=1.13E6
X0=R0IN/(JRC*NUTC)
X1=R1IN/(JRC*NUTC)
X2=R2IN/BIOC
X3=R3IN/BIOC
X4=R4IN/DEADC
X5=R5IN/(DEADC*TID)
X6=R6IN/R4IN
X7=R7IN/(NUTC*TID)
X8=R8IN/RIV
X9=R9IN/(JRC*NUTC)
OMEGAY=2.0*3.1415/365
OMEGAT=2.0*3.1415/14.77
OMEGAO=2.0*3.1415
```

```
DYNAMIC
```

```
RIVER=4.26E5+2.13E5*COS(OMEGAY*TIME)
TIDE=1.13E6+5.65E5*SIN(OMEGAT*TIME)
```

```
NOSORT
```

```
JR=SUN/(1.0+X0*NUT)
SCLAR=SIN(OMEGAO*TIME)
IF (SCLAR .LT. 0.0) SCLAR=0.0
SUN=(9759+6365*SIN(OMEGAY*TIME))*SCLAR
```

```
SCRT
```

```
PU=INTGRL(PUI, FLOWS)
PL=INTGRL(PLI, FLOWL)
FLOWS=X0*JR*NUT
FLCWL=((X2*BIO)+(X3*BIO))
BDOOT=X1*JR*NUT-X2*BIO-X3*BIO
BIO=INTGRL(BIOC, BDOOT)
DOOT=X2*BIO-X4*DEAD-X5*DEAD*TIDE
DEAD=INTGRL(DEADC, DOOT)
NDOT=X8*RIVER+X3*BIO+X6*X4*DEAD-X7*NUT*TIDE-X9*NUT*JR
NUT=INTGRL(NUTC, NDOT)
```

```
TERMINAL
```

```
TIMER FINTIM=3650.0,DELMIN=2.0E-45,DELT=0.01,PRDEL=10.0)
METHOD SIMP
PRINT BIO,DEAD,NUT,PU,PL
```

```
END
STOP
ENDJOB
/*
```

```
//MARSH5 JCB (2002,2002,150,2,0),PAUL.ZWICK,CLASS=1
//STEP1 EXEC CSMP,
//          CCMP=,
//          LKED=
INITIAL
```

```
INCON IQ1=2.6150
INCCN IQ2=2.6150
INCON BIOC1=261.50
INCCN BIOC2=261.50
INCON DEADC=5226.0
INCCN NUTC=523.0
INCON IPU1=0.0
INCCN IPU2=0.0
INCCN IPL1=0.0
INCCN IPL2=0.0
PARAMETER JC=3450.0
PARAMETER JRC=690.0
PARAMETER R0IN=1380.0
PARAMETER R1IN=2.0
PARAMETER R2IN=1.05
PARAMETER R3IN=0.105
PARAMETER R4IN=1.59
PARAMETER R5IN=0.48
PARAMETER R6IN=0.29
PARAMETER R7IN=0.09
PARAMETER R8IN=0.39
PARAMETER R9IN=0.365
PARAMETER R10IN=1380.0
PARAMETER R11IN=2.0
PARAMETER R12IN=1.05
PARAMETER R13IN=0.105
PARAMETER R19IN=0.365
PARAMETER R20IN=1380.0
PARAMETER R21IN=2.69
PARAMETER R22IN=1.05
PARAMETER R23IN=0.105
PARAMETER R24IN=0.69
PARAMETER R25IN=1380.0
PARAMETER R26IN=2.69
PARAMETER R27IN=1.05
PARAMETER R28IN=0.105
PARAMETER R29IN=0.69
PARAMETER RIV=6.3955
PARAMETER TID=1.13E3
PARAMETER C=1.0E-4
FREQ1=1.00
FREQ2=0.00274
OMEGA1=2*3.1415927*FREQ1
OMEGA2=2*3.1415927*FREQ2
L1=1/(C*OMEGA1**2)
L2=1/(C*OMEGA2**2)
CLK1=((IQ1**2)/(2*C))+((L1/2)*(R23IN**2))
CLK2=((IQ2**2)/(2*C))+((L2/2)*(R23IN**2))
XC=R0IN/(JRC*NUTC*CLK1)
X1=R1IN/(JRC*NUTC*CLK1)
X2=R2IN/BIOC1
X3=R3IN/BIOC1
X4=R4IN/DEADC
X5=R5IN/(DEADC*TID)
X6=R6IN/R4IN
X7=R7IN/(NUTC*TID)
X8=R8IN/RIV
X9=R9IN/(JRC*NUTC*CLK1)
X10=R10IN/(JRC*NUTC*CLK2)
X11=R11IN/(JRC*NUTC*CLK2)
X12=R12IN/BIOC2
X13=R13IN/BIOC2
X19=R19IN/(JRC*NUTC*CLK2)
X20=R20IN/(JRC*IQ1)
X21=R21IN/(JRC*IQ1)
X22=R22IN/ID1
X23=OMEGA1**2
X24=R24IN/(JRC*IQ1)
```

```

S1C=R23IN/X23
X25=R25IN/(JRC*IQ2)
X26=R26IN/(JRC*IQ2)
X27=R27IN/IQ2
X28=OMEGA2**2
X29=R29IN/(JRC*IQ2)
S2C=R28IN/X28
TY=365
TM=14.77
TD=1.0
OMEGAY=2.0*3.1415927/TY
OMEGAM=2.0*3.1415927/TM
OMEGAD=2.0*3.1415927/TD
DYNAMIC
RIVER=4.26E5+2.13E5*COS(OMEGAY*TIME)
TIDE=1.13E6+5.65E5*SIN(OMEGAM*TIME)
NQSORT
SCLAR=SIN(OMEGAD*TIME)
IF (SCLAR .LT. 0.0) SCLAR=0.0
JR=SUN/(1.0+X2*X2*NUT*CLOCK1+X10*NUT*CLOCK2)
SUN=(9759+6365*SIN(OMEGAY*TIME))*SCLAR
SORT
JR1=SUN/(1.0+X20*ABS(Q1))
JR2=SUN/(1.0+X25*ABS(Q2))
XPRC1=JR1*ABS(Q1)
XPRC2=JR2*ABS(Q2)
QDOT1=X21*XPRC1-X24*XPRC1-X23*S1
Q1=INTGRL(IQ1,QDOT1)
S1=INTGRL(S1C,Q1)
FLCW23=X23*S1
QDOT2=X26*XPRC2-X29*XPRC2-X28*S2
Q2=INTGRL(IQ2,QDOT2)
S2=INTGRL(S2C,Q2)
FLCW28=X29*S2
XPOT1=(Q1**2)/(2*C)
XKIN1=(L1/2)*FLCW23**2
CLOCK1=XPOT1+XKIN1
XPOT2=(Q2**2)/(2*C)
XKIN2=(L2/2)*FLCW28**2
CLOCK2=XPOT2+XKIN2
BDOT1=X1*JR*NUT*CLOCK1-X2*BIC1-X3*BIC1
BIC1=INTGRL(BICC1,BDOT1)
BDOT2=X11*JR*NUT*CLOCK2-X12*BIC2-X13*BIC2
BIC2=INTGRL(BICC2,BDOT2)
BOUT=X2*BIC1+X12*BIC2-X4*DEAD-X5*DEAD*TIDE
DEAD=INTGRL(DEADC,BOUT)
BOUT=X8*RIVER+X3*BIC1+X13*BIC2+X6*X4*DEAD-X7*NUT*TIDE
-X9*NUT*JR*CLOCK1-X19*JR*NUT*CLOCK2
NUT=INTGRL(NUTC,BOUT)
FLCW0=X0*JR*NUT*CLOCK1
FLCW10=X10*JR*NUT*CLOCK2
FLCW11=X2*BIC1+X3*BIC1
FLCW12=X12*BIC2+X13*BIC2
PU1=INTGRL(IPU1,FLCW0)
PU2=INTGRL(IPU2,FLCW10)
PL1=INTGRL(IPL1,FLCW11)
PL2=INTGRL(IPL2,FLCW12)
TERMINAL
TIMER FINTIM=3650.0,DELMIN=2.0E-45,DELT=0.01,PRDEL=10.0
METHOD SIMP
PRINT BIC1,BIC2,DEAD,NUT
END
STOP
ENDJOB
/*

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BIOGRAPHICAL SKETCH

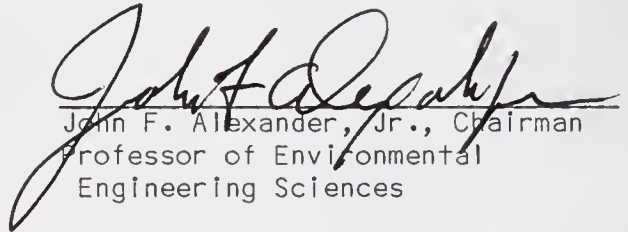
Paul D. Zwick was born on November 26, 1946, in North Canton, Ohio. He graduated from Lompoc high school on June 6, 1964 in Lompoc, California. He served in the United States Naval Submarine service on board the nuclear submarine U.S.S. Woodrow Wi]lson SSBN 624 Gold from 1966 to 1971, after which he operated commercial nuclear power plants from 1972 to 1974.

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Research for this dissertation was carried out at the University of Florida, Gainesville.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



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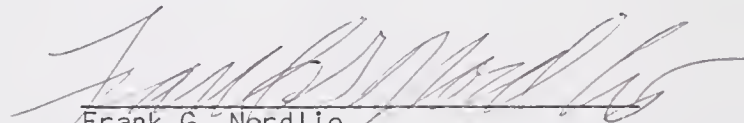
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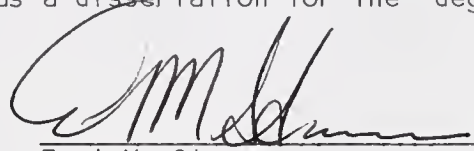
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This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December 1985



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